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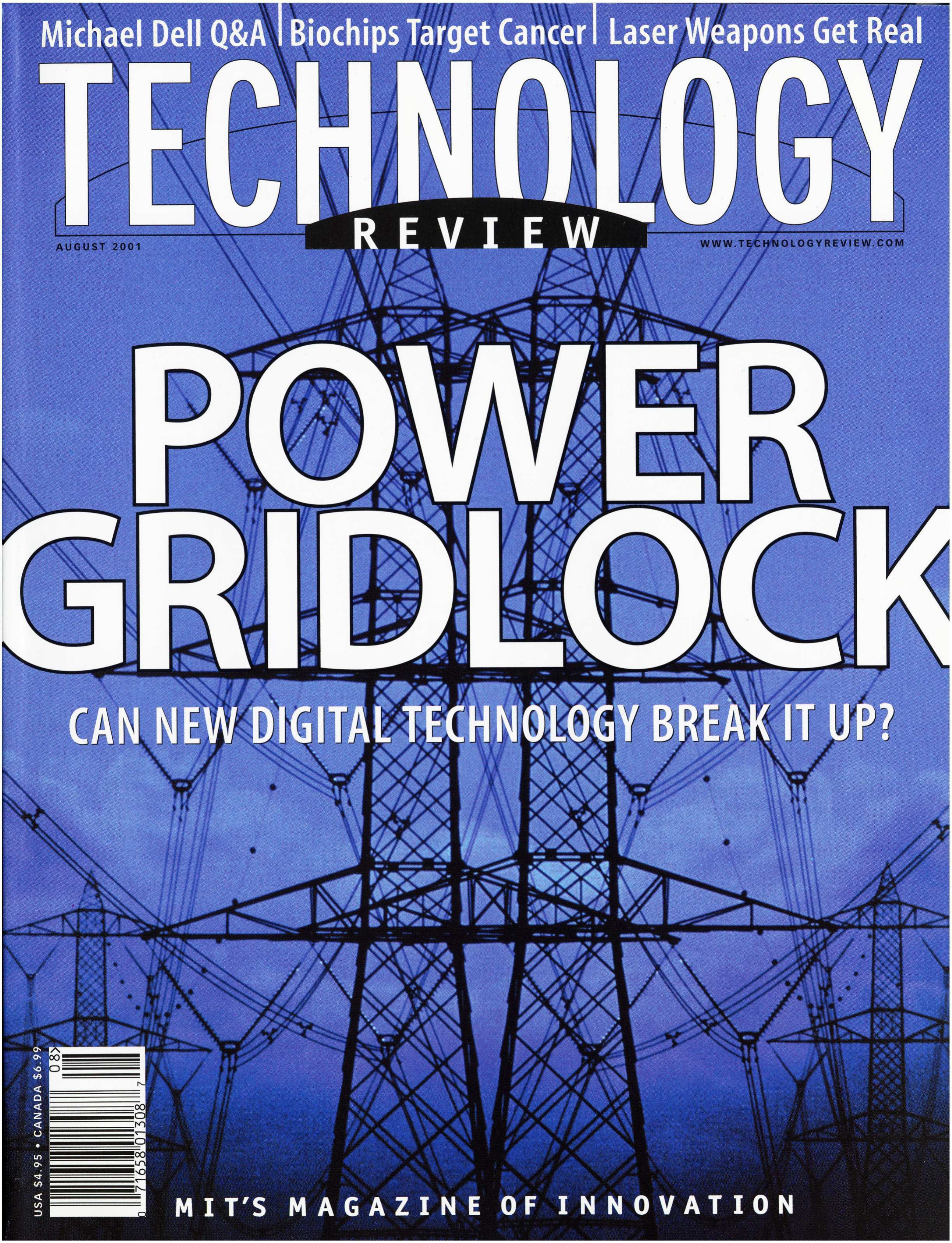

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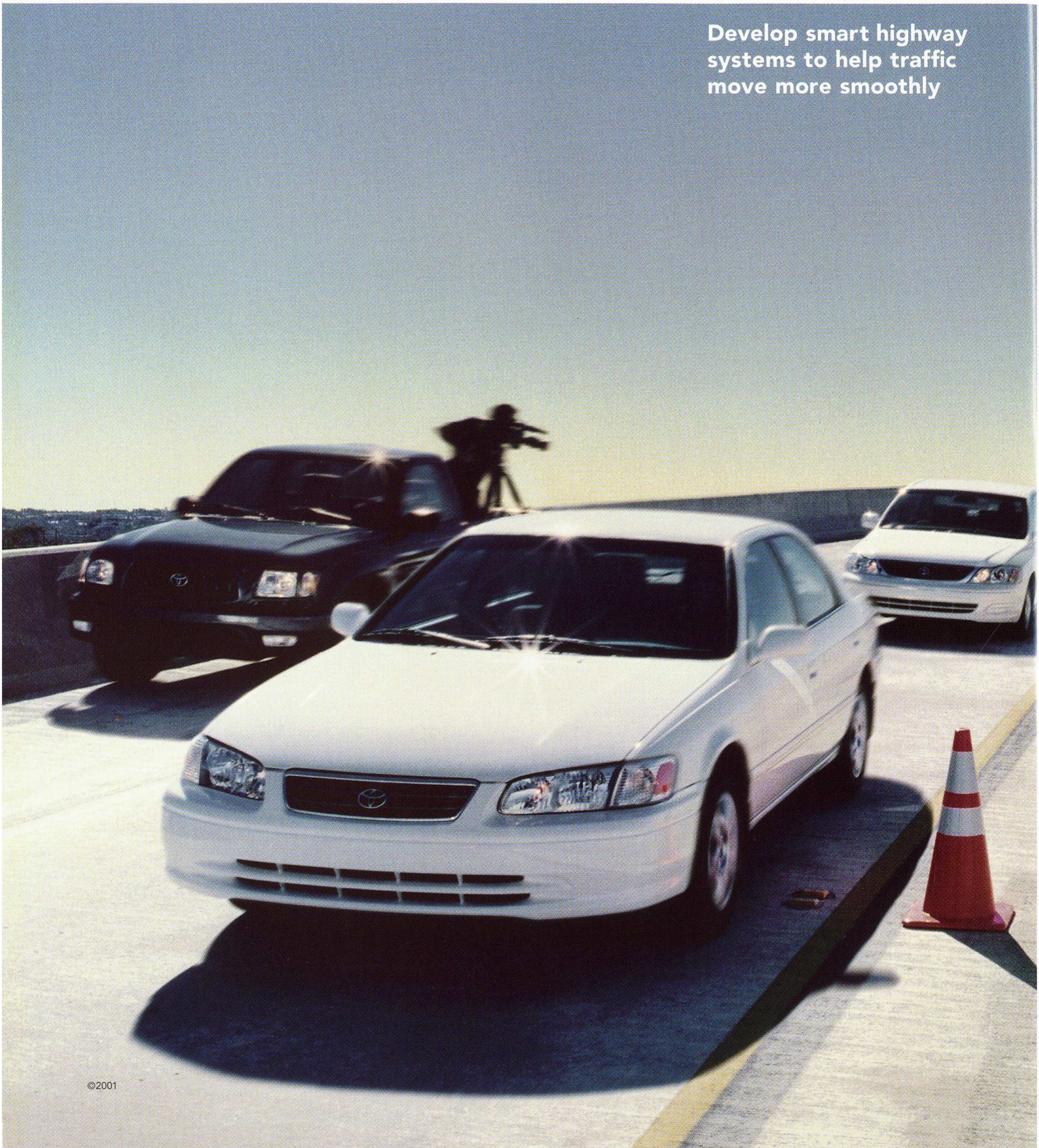

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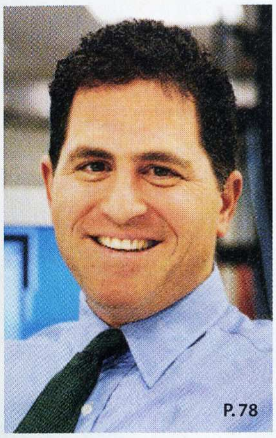

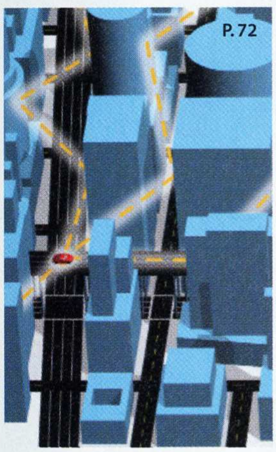

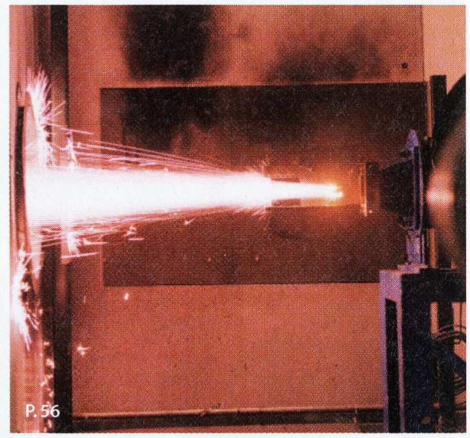

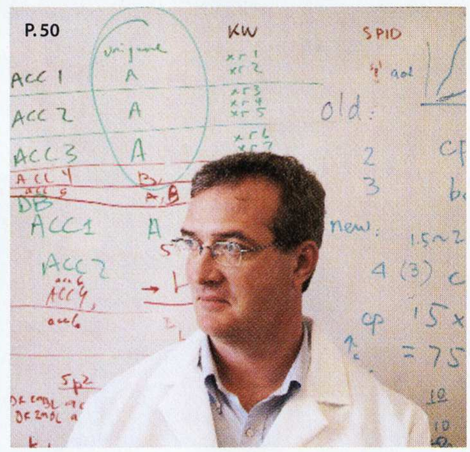

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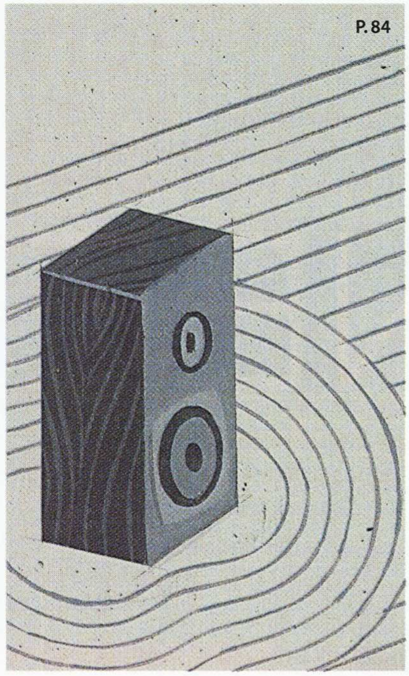
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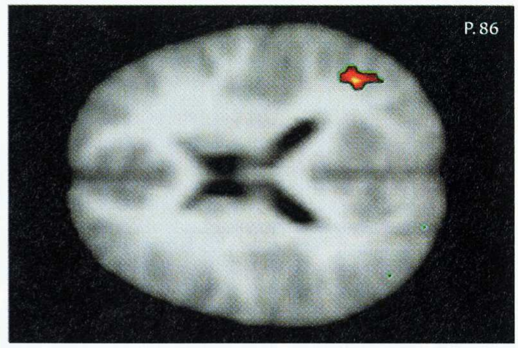
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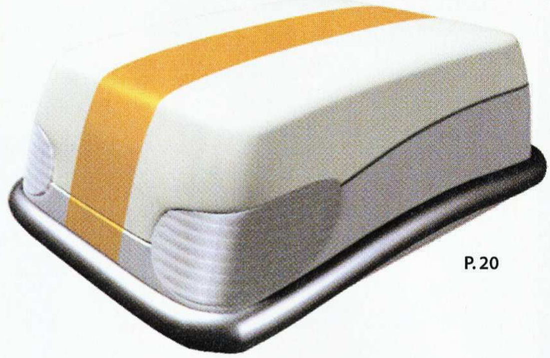
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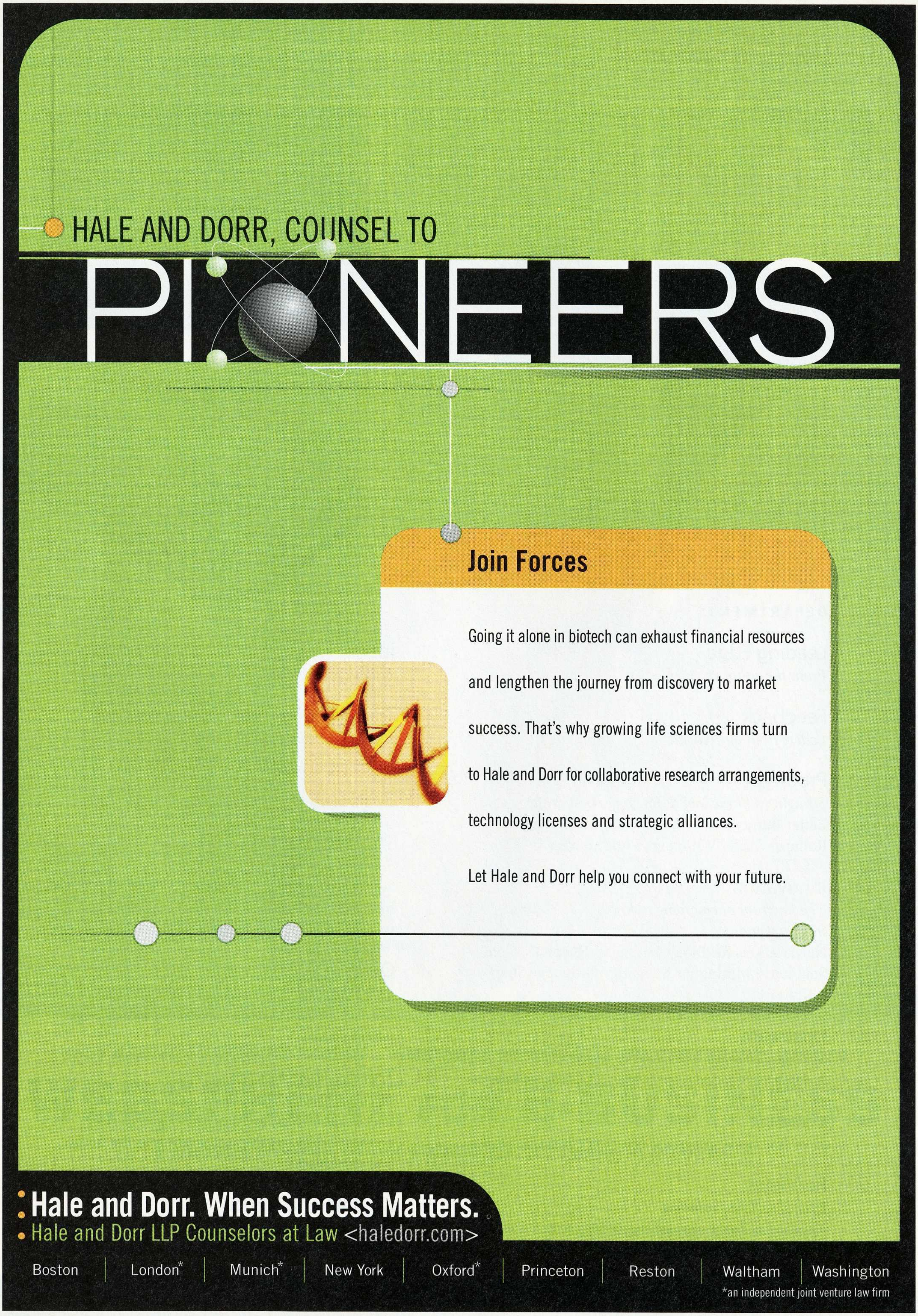
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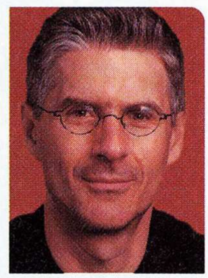
LEADING EDGE *From the Editor in Chief*

Surge Protector

THERE'S BEEN NO SHORTAGE OF NEWS COVERAGE OF THE POWER crisis in California and the Bush administration's energy policy. Still, all those articles have managed to miss a key part of the story: how the electric power grid actually works, and what effect new technology might have on the shortages that already beset California and are imminent in other parts of the country. Like the air traffic system or the telephone system, the power grid remains one of those gigantic human constructions that lurk in the background of policy controversies but never make it into the light of day. *Technology Review* is changing that.

Peter Fairley's meticulously reported story in this issue *("A Smarter Power Grid," p. 40)* offers an introduction to the tangle of wires that carries the juice from where it's generated to where it's consumed. The grid was built half a century ago and served us well for decades, but it hasn't aged well. Particularly since the rapid deregulation of the power production industry in the last decade, the grid has become overburdened and fragile, prone to temperamental displays and dramatic funks.



What is more, at a time when California (and increasingly the rest of the country) is crying out for power, the creaky old grid is hiding a huge amount of capacity that cannot be used, because it would push the wild tangle of wires closer to meltdown. One way to get at this hidden capacity is to apply modern digital switching techniques to the transmission of power in an approach known as "power electronics." When two high-voltage AC lines—the kind that carry power across counties and states—run parallel, for example, power electronics makes it possible to switch the load from one to the other.

Until now, that's been a very difficult task. But power electronics can reshape the alternating current in each line to affect resistance, allowing operators to allocate power between the two lines. By routing power where it's needed during times of peak load, and generally keeping the system better balanced, power electronics could prevent future crashes. The technology would also enable consumers to tap into the existing system's unused capacity. That desirable outcome could emerge in parallel with the political and economic changes needed to make sure we avoid an energy catastrophe.

But it won't happen overnight. As with all modifications of global systems, the introduction of power electronics will happen in increments, gathering momentum until it transforms the whole crazy-quilt power grid. (Think of fiber optics, threading its way through the telecom system.) This change is already under way in marginal elements of the power grid.

Now, Fairley tells us, the first major experiment is going online. At a switching station in Marcy, in upstate New York, power electronics is being put in place to juggle transmission between two giant electrical conduits that service New York City. If this experiment works, it could provide a model for upgrades in many other areas of the system, unleashing considerable entrepreneurial energy in the process.

No matter how well this experiment works, we will still need to wrestle with the demons unleashed by deregulation, and think about better ways to moderate our ravenous appetite for kilowatts. But new technology does offer novel and enterprising tools for dealing with the coming power crunch. And you'll read about them first in *Technology Review.* **—John Benditt**

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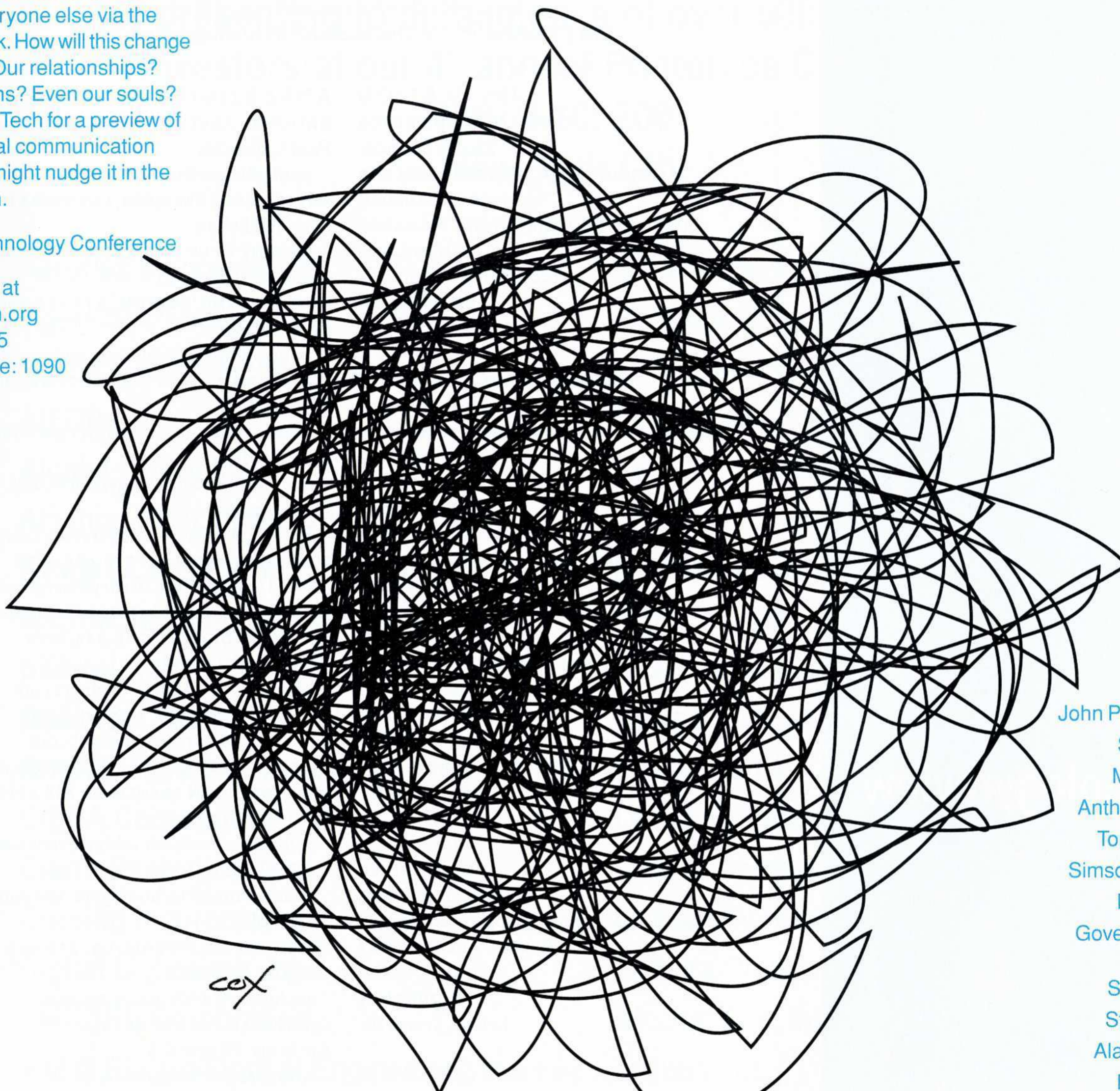

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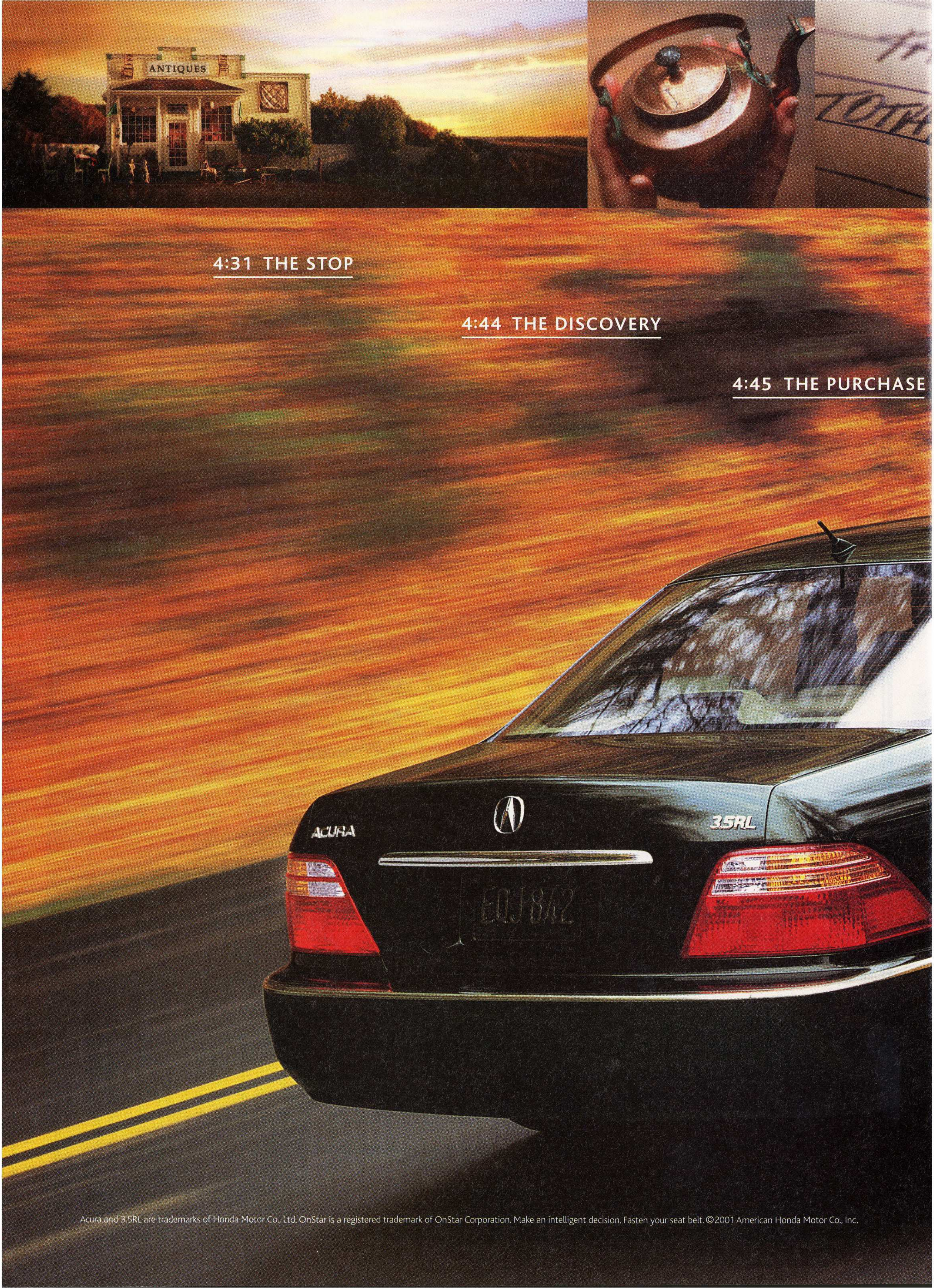
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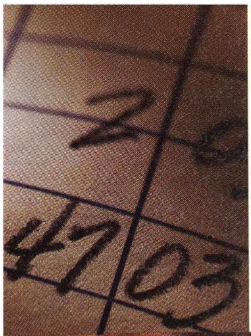

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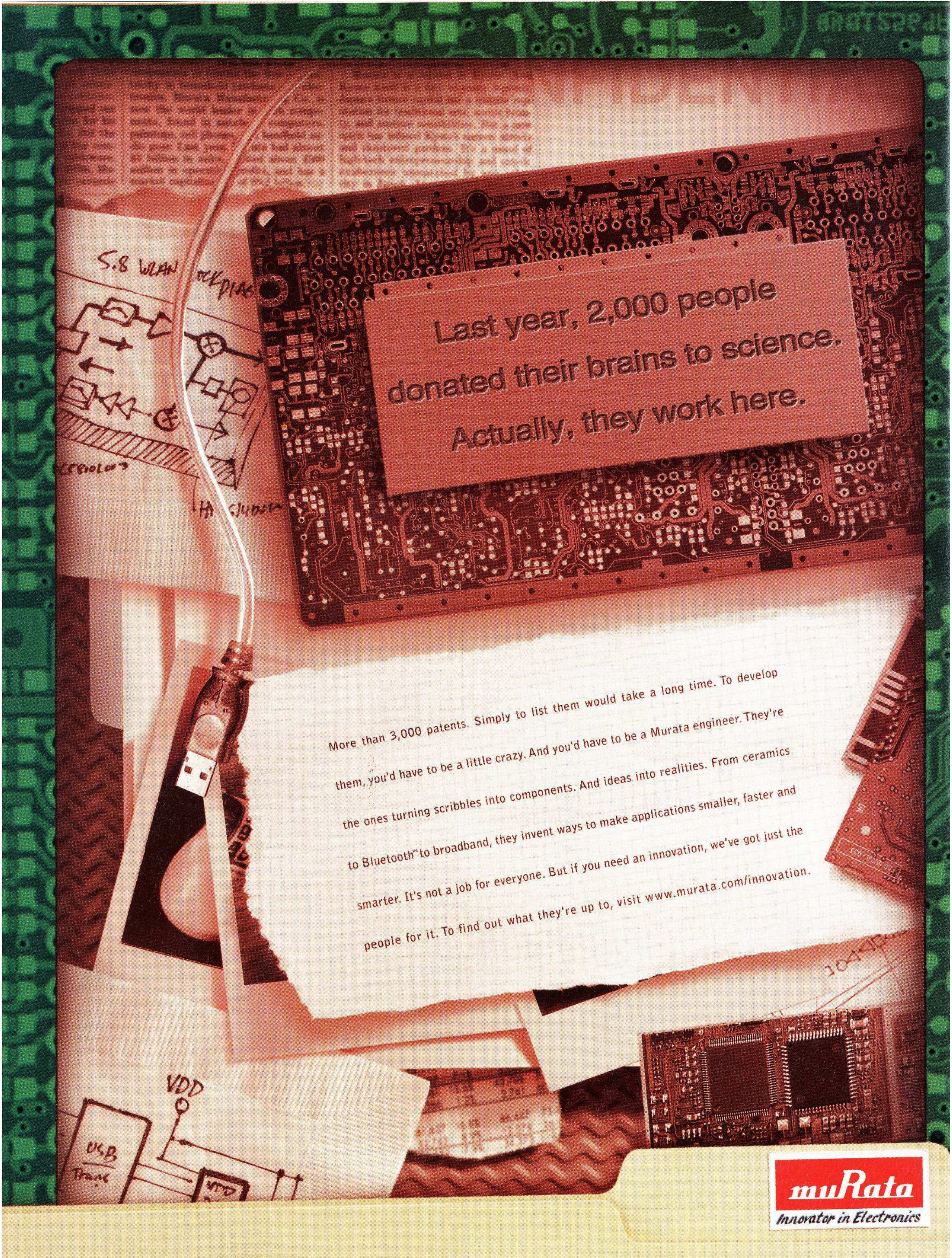
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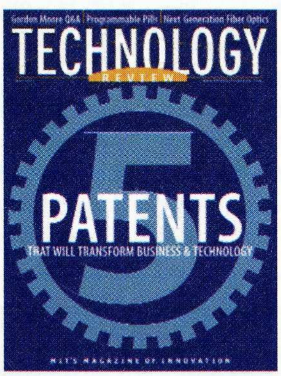
"An inventor is entitled to a patent for a creation that is new, nonobvious and useful. The PB&J patent Shulman so disparages is all three."

Patent Problems

THE COVER THEME OF THE MAY ISSUE, patents, is somewhat at odds with the theme of innovation running throughout *Technology Review*. While the U.S. patent system can be part of the reason that American companies innovate, it is also part of the reason that innovation is so difficult. Some companies accrue patents out of self-protection from the legal system; many others do so out of greed and the desire to prevent their competitors from innovating.



Instead of simplistic articles about interesting patents (which in fact could just as easily be articles on interesting innovations), *Technology Review* should take a much more thoughtful look at whether the U.S. patent system is helping or hurting innovation, particularly for smaller companies. You will probably find that the system works against innovation in general, while supporting innovation only for the richest few companies.

PAUL HOFFMAN
Santa Cruz, CA

THIS IS RIGHT UP THERE WITH THE 1988 Calgary Olympic committee thinking they had such an exclusive right to the word "Olympic" that they could threaten long-existing small businesses with "Olympic" in their names to make them rename their companies.

It's what happens when there are too many lawyers sitting around with too much time on their hands. They have to do something to justify their existence.

RON CRUICE
Gibbons Landing, British Columbia
from TR*'s Web forum*

I JUST WANT TO KNOW how much it's going to cost everyone now to make a PB&J sandwich.

NANCY HUGHES
Milledgeville, GA
from TR*'s Web forum*

Spreading It On Thick

PB&J NEEDS FURTHER PATENT-LAW research ("PB&J Patent Punch-up," *TR* May 2001). Strawberry jam and/or preserves would appear to be the preferred fruit spread to accompany peanut butter, with grape jelly running a close second. But personally, I prefer the tang of marmalade (PB&M), a preference that would, of course, require further patents and subpatents for orange marmalade, grapefruit marmalade, and so on.

In short, I've learned that to micromanage most anything is to embrace absurdity.

W. TEMPEL
Santa Clara, CA

SETH SHULMAN'S "PB&J PATENT Punch-up" was clever, but it skirts the truth. Under our Constitution, an inventor is entitled to a patent for a creation that is new, nonobvious and useful. Accept it or not, the patent that Shulman so disparages is all three. By surrounding the jelly with peanut butter—not only top and bottom but around the periphery where crustless bread is crimped—the patent owners keep the jelly from migrating into the bread. They more than meet the patent requirements.

As a patent agent and sometime inventor in the edible arts, I wonder at the sheer ingenuity that can take something so utterly common and produce a new wrinkle. Our legal system, including the world of patents, works. We all can cite examples of overreaching, but in the long run it shakes out. Bad patents are invalidated, bad actions are proscribed and the marketplace rewards the worthy and the lucky.

EDWARD KALISKI
Greenville, DE

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Seth Shulman responds:
I'm still looking for more nominees for readers' favorite examples of intellectual-property overreach. They are out there all over the place, and many of you undoubtedly have to deal with them as part of your work.

Here are a few worthy contenders from the world of trademark law that I didn't have space for in the column. Like the PB&J, some of these cases are humorous, except that, too often, the problem they represent is no laughing matter. For example:

- Lawyers at AOL Time Warner threatened legal action against a 15-year-old girl from Singapore to force her to surrender the rights to the domain name harrypotternetwork.net. The company claims "Harry Potter" as its intellectual property. Now if you type in the harrypotternetwork.net URL, it directs you to www.hpnetwork.f2s.com, the girl's fan site, where she and her friends post comments and discussions about the popular book series.
- Pillsbury threatened suit against Columbia University software engineers who used the term "bake-off" for an event for engineers to check the compatibility of their software. It seems Pillsbury has trademark protection over the term "bake-off"—and felt that some folks might think the engineers were baking cookies.
- Or how about Uncle Milton Industries, which owns and zealously protects its trademark on the words "Ant Farm"? I don't know who the aggrieved parties are in this one, but a company spokeswoman explained to a reporter that anyone who decides they want to sell a bunch of ants behind glass in the United States is legally obligated to advertise the product as a "formicarium."

Chew on This

THE ARTICLE ON ORAL VACCINES "Five Patents to Watch: Healthy Snacks" (*TR* May 2001), by Erika Jonietz, left me puzzled. All the antigens produced by transfer of microbial genes to plants appear to be proteins. One should expect that, on ingestion, the protein would be digested by proteases and broken into pieces of peptide size. If unaffected by proteases, how does the antigen pass into the bloodstream to do its work? Hasn't this situation been the reason we do not have oral insulin?

LEONARD STOLOFF
Delray Beach, FL

Erika Jonietz responds:
Tests on both animals and humans have shown that the proteins in edible vaccines do make it through the digestive system and successfully stimulate immunity to the bacterium or virus they come from. Researchers believe the tough outer wall of plant cells acts as a shield for the proteins, protecting them from stomach acids. When the wall starts to break down in the intestines, the cells gradually release the proteins, which enter the bloodstream through the same route food proteins take; once in the blood, the proteins stimulate circulating immune cells. (Special immune cells in the gut also take up the proteins and respond by creating an immune response specific to the membranes lining the nose, mouth and intestines—something injected vaccines do poorly, if at all.) Ingestible versions of protein drugs like insulin generally lack any sort of protective barrier, like the one plant cells naturally provide in edible vaccines. As a result, they are indeed vulnerable to breakdown during digestion.

Feel the Power

THE IDEA OF DISTRIBUTING ELECTRIC-power generation capability throughout the system rather than centralizing it at a few big utility-run plants ("Power to the People," *TR* May 2001) is somewhat new, but I don't think that, for consumers, the economics are going to add up. Most homeowners are not going to want to spend $10,000 or more only to gain partial independence from their local power company.

Power companies, however, might find that creating a "virtual power plant" yields a real economic advantage. The distribution is already taken care of. Utilities could contract with companies to buy home generators in several standard sizes. If the economics could be worked out, the virtual power plant might provide an attractive alternative to, or at least augmentation of, a series of nuclear power plants. Another advantage would be the relative ease of performing maintenance on small, simple generators rather than very large complex systems.

MICHAEL BORDEN
Culver City, CA

IN "POWER TO THE PEOPLE," WAYNE Gardner of Exelon Capital Partners is quoted as saying that deregulation now permits microturbines and other forms of distributed generation. I practiced energy law for 40 years and I never encountered any law prohibiting private generation. What made it infeasible was economics. Except in the case of cogeneration (in which the leftover steam from electrical generation is used for heating), it was impossible for a

small system to compete in price and quality of power with power from the grid. Innovation has made available microturbines and fuel cells that make it possible for private generation to be competitive with generation from integrated systems of bulk power supply. But up until now technological barriers—not the law—prevented widespread use of distributed generation.

WALLACE EDWARD BRAND
Washington, DC

THE BIGGEST HANG-UP WITH DIStributed power generation is the old paradigm of being dependent upon the local utility. People and businesses have not become fully aware of the need to become independent of the grid; they are all stuck on the interstate, in traffic!

WILLIAM MONTJOYE
San Antonio, TX

Unseen Assumptions

ONE THING THAT STRUCK ME ABOUT "Battle for the Unseen Computer" (*TR* May 2001) was the assumption that each embedded device would stand alone. If designers considered embedded devices as part of a larger system (an information grid, to use the current term), then using Linux or other Unix-based operating systems would make sense. Almost every distributed-operating-system project that I am familiar with is derived from the basic structure of Unix.

Items that are grouped together, such as the small computers in a car, or household appliances within a house, would then become nodes in a larger and more powerful cooperative system.

Just because embedded devices are small doesn't mean software designers shouldn't think big.

ARTHUR MAJOOR
London, Ontario
from TR*'s Web forum*

WHEN I READ OR HEAR DISCUSSIONS of embedded systems, I encounter "embedded" and "real-time" being used interchangeably. Does the link between the two still exist? Or is it just a "historical by-product." It seems to me that, initially, embedded operating systems were developed to control, say, rocket fuel valves and blenders, without much distinction between the two. In that case, it seems, both had to be "tiny," but there was a vast difference in the need for "real time"—or maybe there was no need to make a distinction.

With the massive increases in memory coupled with the proliferation of embedded systems, there is arising a whole class of appliances that can do fine with an operating system that (a) is not real time or is "soft" real time and (b) must have a small but not necessarily "tiny" footprint (the Internet radio from the article seems a good example of this to me).

I read or hear references to this class of appliances often in discussions of embedded systems, but I never encounter the idea that there might arise two distinct classes of embedded operating systems, one to handle each distinct class of appliance. So instead of standardizing on only one operating system or trying to develop one set of standards to serve both, two sets of standards (or standardization around two operating systems, etc.) might be a better direction.

SLADE STEWART
Roswell, GA
from TR*'s Web forum*

PROTOTYPE

STRAIGHT FROM THE LAB: TECHNOLOGY'S FIRST DRAFT

VITO ALUJA

Better Burger Box

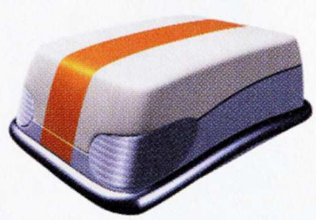
Facing environmentalists' ire, fast-food franchises switched from polystyrene burger boxes to cardboard several years back. Now diners gripe about cold food. U.S. Department of Agriculture researchers are cooking up a solution to make everyone happy: cheap, biodegradable containers derived from a source consumers are more familiar with from buns—wheat. Chemists at the USDA's Agricultural Research Service in Albany, CA, made a foam from the starch inside wheat kernels and mixed it with fibers from wheat stalks to add strength. Boxes made from this foam are as strong as polystyrene containers and insulate far better than cardboard. They're also cheaper than the eco-friendly alternatives now in use—including a similar material made from potato starch. The researchers are close to solving the boxes' main weakness: a tendency to soften when wet. Several companies have expressed interest in the new material; your burger could come in a wheat-based box in two or three years.

Voice ID

Some smart cards include a digital template of the owner's fingerprint so users won't have to remember PINs or passwords when, for instance, making purchases over the Web. But the idea of fingerprinting bothers many people. Swindon, England-based Domain Dynamics is putting voice templates on smart cards, so users can authenticate transactions using their voices. Standard voiceprints require the storage of more data than can fit on the chip embedded in a smart card; but Domain Dynamics' voiceprints are one-tenth that size. Conventional methods describe voice based on the amplitude of sound waves at millisecond intervals, but Domain Dynamics uses a simpler method that describes each wave's overall shape. When a user speaks, the card's tiny processor matches the voice with the stored template. Domain Dynamics is working with several companies to make the technology available for banks as well as for cell phones and personal digital assistants; the goal is a product within the next two to three years.

Machine Maid

The days of floor-cleaning drudgery may finally be over. Erwin Prassler and his colleagues at the University of Ulm, Germany, have designed a cleaning robot that moves about in a room without damaging the furniture. As the robot moves, a towel attached to its base runs through a container filled with a cleansing liquid and scrubs the floor. Two computer-controlled motors drive the robot, and a sensor-based navigation system lets the robot find its way around obstacles. The robot weighs less than 10 kilograms and would be suited for homes and restaurants. Prassler is discussing commercialization with a U.S. appliance maker and expects the robocleaner to reach the market in two to three years.


COURTESY OF UNIVERSITY OF ULM

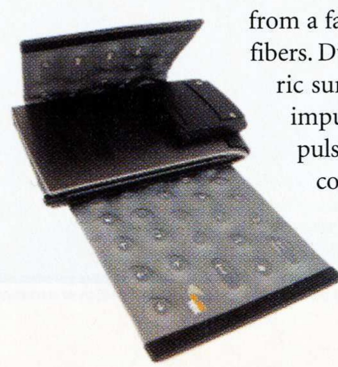
Microbial Prospectors

A gram of soil can harbor more than 10,000 species of microscopic organisms. Subtle differences in the local environment—say, gases seeping from a petroleum deposit far below—can affect which microbes wind up in a plot of dirt. Mill Valley, CA-based startup Taxon hopes to take advantage of these phenomena to go prospecting for oil and other valuable resources.

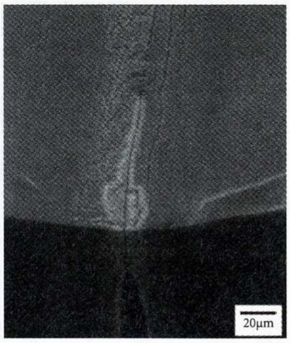
Taxon uses DNA sequencing and other techniques to generate for each soil sample a genetic profile—an indication of which species are present and in what proportions. The idea, says chief science officer Matt Ashby, is to analyze soil near known deposits of oil, gold, platinum and other valuable materials to find signature microbial profiles. Then, says Ashby, these signatures could provide the basis for quick handheld testing devices that prospectors could use in the field. Taxon, which was launched last September, is working with the U.S. Department of Energy to develop its first profiles, on soil from an oil field in Wyoming.

Keyboard Rollups

Typing on a handheld device's tiny keypad can be frustrating. It's not uncommon to have to press the same key several times just to create one letter. Now, ElectroTextiles, based in Buckinghamshire, England, has designed a full-sized flexible keyboard that can be attached to a cell phone or a personal digital assistant. When you're done, fold it in thirds and tuck it into your jacket—it takes up about the same space as a handheld computer. The keyboard is only a few millimeters thick, made from a fabric woven with tiny conductive fibers. During typing, pressure on the fabric surface is converted into electronic impulses. Software translates the impulses into digital commands that become the letters and words of your e-mail message. ElectroTextiles plans to bring the keyboard to market late this year.


COURTESY OF ELECTROTEXTILES

Wafer Whoppers


COURTESY OF UNIVERSITY OF STUTTGART

Microchip manufacturers etch their chips, more than 100 at a time, on large, round silicon wafers. The bigger the wafer, the greater the number of chips—and the lower the per-chip cost. The problem is that silicon crystals—from which wafers are harvested—cannot be grown to diameters larger than about 30 centimeters without being riddled with defects. Now, Juergen Werner and his colleagues at the University of Stuttgart, Germany, have found a way to get large wafers by joining smaller ones. They lay two wafers side by side and crystallize silicon vapor between their edges to close the gap. In early work, Werner connected two one-by-three-centimeter wafers; the technique should work to seal together larger wafers as well. The same method should also work with germanium—whose crystal growth is limited to 15 centimeters—to produce large wafers for more efficient solar cells and electronic displays.

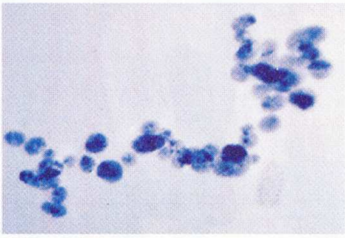
Have Web, Will Travel

For all the hype about a wireless Web, mobile users who log on find that there's not much there, there. Today's Web-enabled cell phone can display only the handful of sites that your wireless communications provider has partnerships with: your carrier decides what subset of the Internet you are able to see. An Oakland, CA, company called PocketThis has software that lets you choose Web content that you want to access—even while you're on the road.

While at your desktop PC, you open a Web page—or other application window—and highlight whatever information you'll want to see from your cell phone. Clicking a button sends the information to the PocketThis server. To view that same information remotely, you simply connect from your cell phone or PDA to the server, which can also retrieve the most up-to-date information on such things as stocks or online product prices. The PocketThis software is in market trials in the United States as well as in France and Britain—where, according to chief strategy officer Jonathan Sheena, people already think of phones as "something they can type into."

Test of Gold

Monitoring heavy metal contaminants—such as lead, mercury and cadmium—in rivers and wells requires multiple trips to the lab for analysis with expensive and bulky equipment. A team of chemists headed by Joseph T. Hupp at Northwestern University has a more efficient method that could be adapted to make a portable device for testing samples in the field. Hupp's group starts with nanoscale-sized particles of gold, each smaller than a virus. They then coat the particles with molecules that are able to bind with the heavy metals. Water containing the particles naturally assumes a deep shade of red. But if, for example, lead ions are present, they attach to the receptors, causing the gold particles to aggregate and turn the water blue. The greater the lead concentration, the more dramatic the color change. Then, to determine the exact quantity of heavy metal in the water, the Northwestern researchers measure its absorption of ultraviolet light. While not as sensitive as standard tests, the nano method's speed and low cost make it an attractive alternative.


COURTESY OF AMERICAN CHEMICAL SOCIETY

Gold nanoparticles clump and turn water blue to show the presence of lead.

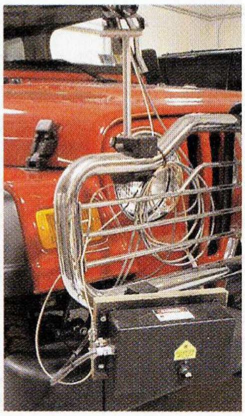
Stroke Sensor

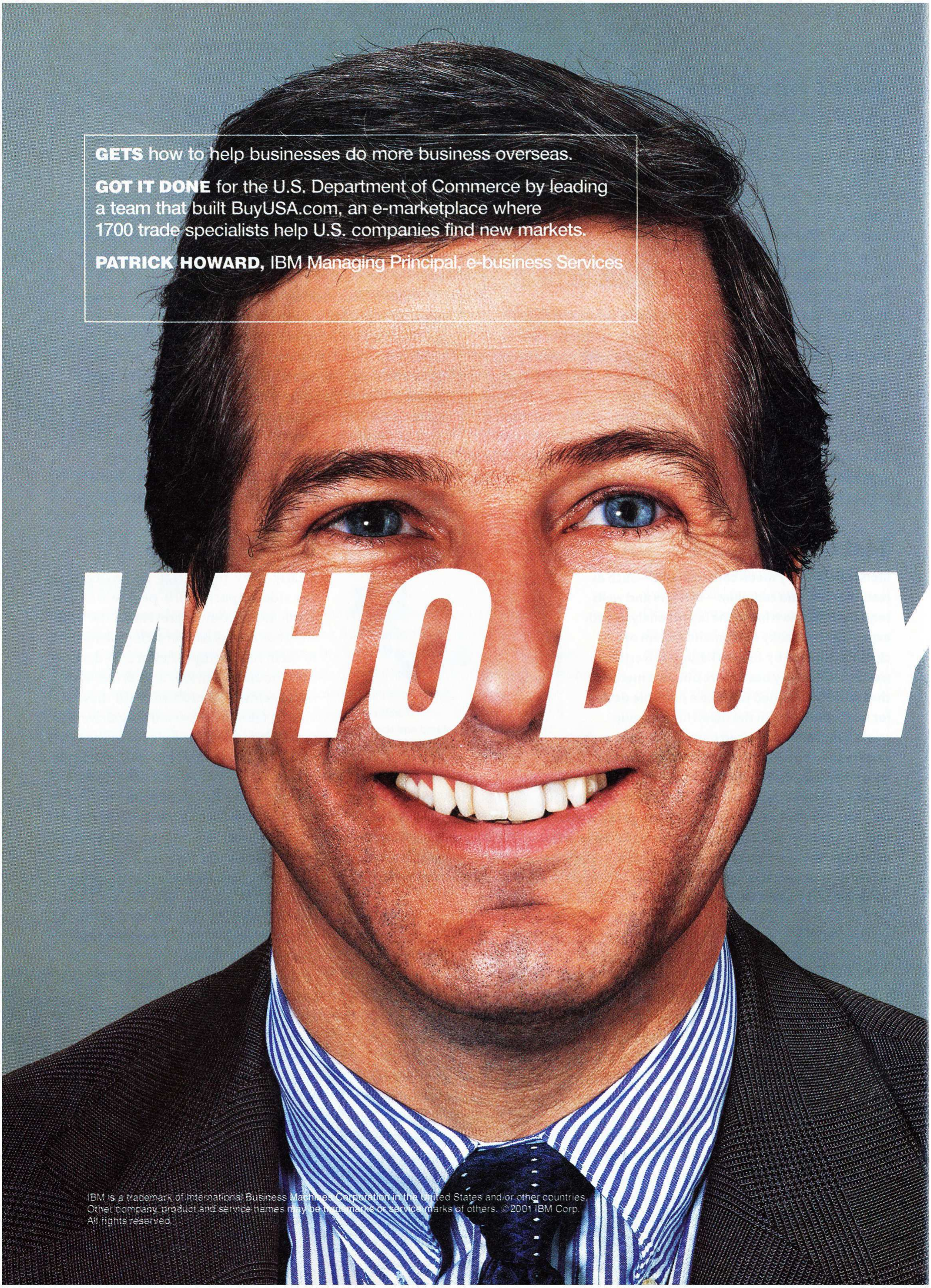
Each year, strokes afflict about 600,000 Americans—killing almost 160,000 and disabling many others. Most occur without warning. Magnetic resonance imaging and arteriograms can detect conditions that presage stroke but are expensive, time consuming and sometimes painful. A new sensor that sits on the eyelid may provide a cheap, noninvasive method of screening for brain aneurysms (bulges in blood vessels that can burst, depriving the brain of blood) and for blockages that can limit blood to the brain.

Electronics engineers in Kenji Kobayashi's lab at Takushoku University in Hachioji, Japan, developed the thin plastic sensor, which detects the vibrations caused by blood flow. Aneurysms and blockages change the flow and hence the vibrations. In tests, the device accurately detected aneurysms small enough for surgeons to repair before they were likely to bleed; it also identified vessels that had narrowed by 30 percent. Additional testing is needed before the device is considered reliable enough for clinical use.

Laser Bumpers

Nearly forty percent of all bus crashes are side impacts with people or cars. While not all can be prevented, the difficulty bus drivers have in seeing what's next to them has prompted efforts to develop side-mounted sensors and driver-warning systems. One problem with these devices is false alarms—warning drivers of pedestrians safely strolling down the sidewalk, for instance. A group at Carnegie Mellon University's Robotics Institute has created a laser-and-camera system that would sense the presence of a curb, alerting the driver only to obstacles between the bus and the curb. "If you know where the curb is, you can cut down on unnecessary alarms," says research associate Christoph Mertz. The device, funded by the Federal Transit Administration, shoots out low-power laser beams and determines the distance to an object in a beam's path by triangulating the beam with the line of sight of a camera mounted nearby. The system worked well on a test car this spring; field tests on a Pittsburgh bus are scheduled for July.


COURTESY OF CARNEGIE MELLON UNIVERSITY


GETS how to help businesses do more business overseas.
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CORVETTE

The DVD Rebellion

Buy a copy of *The Matrix* on DVD and take it home. Play it on a Mac or on a Windows PC and you're in for a pretty good time. But play it on a PC running the Linux operating system, and the movie industry says that you're breaking the law.

Your transgression is that of "circumvention," a criminal act created by the 1998 Digital Millennium Copyright Act. You see, the video on DVDs is scrambled. Windows and Macintosh DVD players licensed by the DVD Copy Control Association contain the algorithms to unscramble the signal. The Linux DVD player contains these secrets as well. But since the Linux-based program isn't licensed, using the software constitutes an illegal circumvention of copyright management.

DUNG HOANG

Things have gotten nasty as this new crime gets its tryout in the legal system. Last year, eight major film studios, all members of the Motion Picture Association of America, sued the magazine *2600* for posting on its Web site a program that unscrambles DVDs. Not only did the organization win its case, but U.S. District Court judge Lewis A. Kaplan even barred *2600* from posting links to other sites that contained the program. That case is now on appeal.

For the movie industry, the DVD case is about piracy and revenue protection. For the programmers among us, the attempts to suppress this software are an attack on fundamental freedoms of speech and inquiry. It is a battle the movie industry is sure to lose. The only question is, "when?"

At the core of the controversy is technical data about the copy protection techniques used to make DVDs. The information on each DVD is protected by an encryption scheme called the Content Scramble System, or CSS. This technology prevents computer users from duplicating a movie, compressing it down to fit on a CD-ROM, and then giving copies to their friends. Playing the DVD entails decrypting the data—an act that used to require a licensed DVD player with the appropriate descrambling algorithms, stored either in a program or in a set-top box.

Then in 1999, an anonymous European programmer cracked the code and distributed a program—called DeCSS—over the Internet. Ever since, the movie industry has been filing lawsuits and sending threatening letters to individuals and businesses that distribute this and related DVD decryption programs.

How did we get here? In the 1980s, compact discs revolutionized high-fidelity sound. But CDs were not well suited for movies: their roughly 600 megabytes could store barely 10 minutes of video. (Advanced compression systems can put an entire movie on a CD, but the quality suffers.)

Enter DVDs, which can store more than two hours of compressed video on a disc the same size as a CD. If you want to make your own DVDs, you can buy a recording drive for less than $500. Rewritable discs that hold 4.7 gigabytes cost about $30.

It's easy to see why the movie studios are worried. The price of recordable DVD discs is sure to fall. Three years ago, writable CD-ROMs cost $2; today, they're 40 cents or less. Expect writable DVDs for $5 by mid-2002. Equipped with programs like DeCSS, consumers will be able to make high-fidelity copies of DVDs on the cheap.

Movie studios have long been terrified of home recording technology. In 1983, Sony and Universal City Studios

faced off over the legality of home videocassette recorders. Universal said VCRs should be outlawed because they could be used to make illegal copies of copyrighted materials. But in 1984, the U.S. Supreme Court ruled that "the sale of [VCRs] to the general public does not constitute contributory infringement of respondents' copyrights." The Court reasoned that recording a television show at one time for viewing at another fell under the "fair use" provision of copyright law.

For the movie industry, the issue is piracy. But for programmers, the attempt to suppress DVD unscrambling software is an attack on fundamental freedoms of speech and inquiry.

The movie industry has never been happy with this decision, and in 1998 it prevailed upon federal lawmakers to do something about it. Unable to overturn a Supreme Court ruling, Congress did the next best thing: it passed the Digital Millennium Copyright Act, which created the crime of "circumvention."

Copyright is supposed to balance the rights of publishers and the rights of the public, explains Cindy Cohn, legal director of the Electronic Frontier Foundation, a civil-liberties organization defending *2600* magazine. The new law, says Cohn, makes an end run around fair use by making it illegal for any person to use or distribute technologies that can circumvent a copyright protection system. Because of the public's right to fair use, Cohn says, "every time the content holders have tried to reach out and get more control, as they did with VCRs, the Supreme Court has slapped them down."

It isn't just movies that could fall under this new form of protection. Any company that wants to prohibit fair use can simply wrap its products—movies or books or magazine articles—in a thin layer of cryptography. The content purveyor could then apply restrictions that made it possible to view the material only by using the publisher's proprietary software. If the software doesn't allow fair-use rights, then the 1998 legislation makes it illegal for people to circumvent that software to get their rights back.

The original 1999 program that broke the DVD encryption algorithm was created not for piracy but to let people who bought DVDs play them on computers running Linux. But science marches on. In March 2001, two programmers at MIT reduced the original 215-line decryption algorithm to just six lines. It has become so small that people are putting it at the bottom of e-mail messages as a "signature." You can even purchase a T-shirt displaying the forbidden code. *Technology Review* would probably not consider printing a 215-line program; the six lines appear below. "The shorter the program gets, the sillier the studios look for trying to suppress it," says Carnegie Mellon computer scientist Dave Touretzky, who posts a gallery of DVD decoders on his Web site.

Another front in the DVD wars has opened up at Princeton University.

THE DVD UNSCRAMBLER

Six lines of code that have rattled the movie industry

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In April, the Recording Industry Association of America sent computer science professor Edward Felten a chilling letter stating that Felten's publication of a paper on the Secure Digital Music Initiative's watermarking algorithm might constitute a criminal act. Felten pulled the paper from its scheduled release at a conference. Since then, however, it has been all over the Internet.

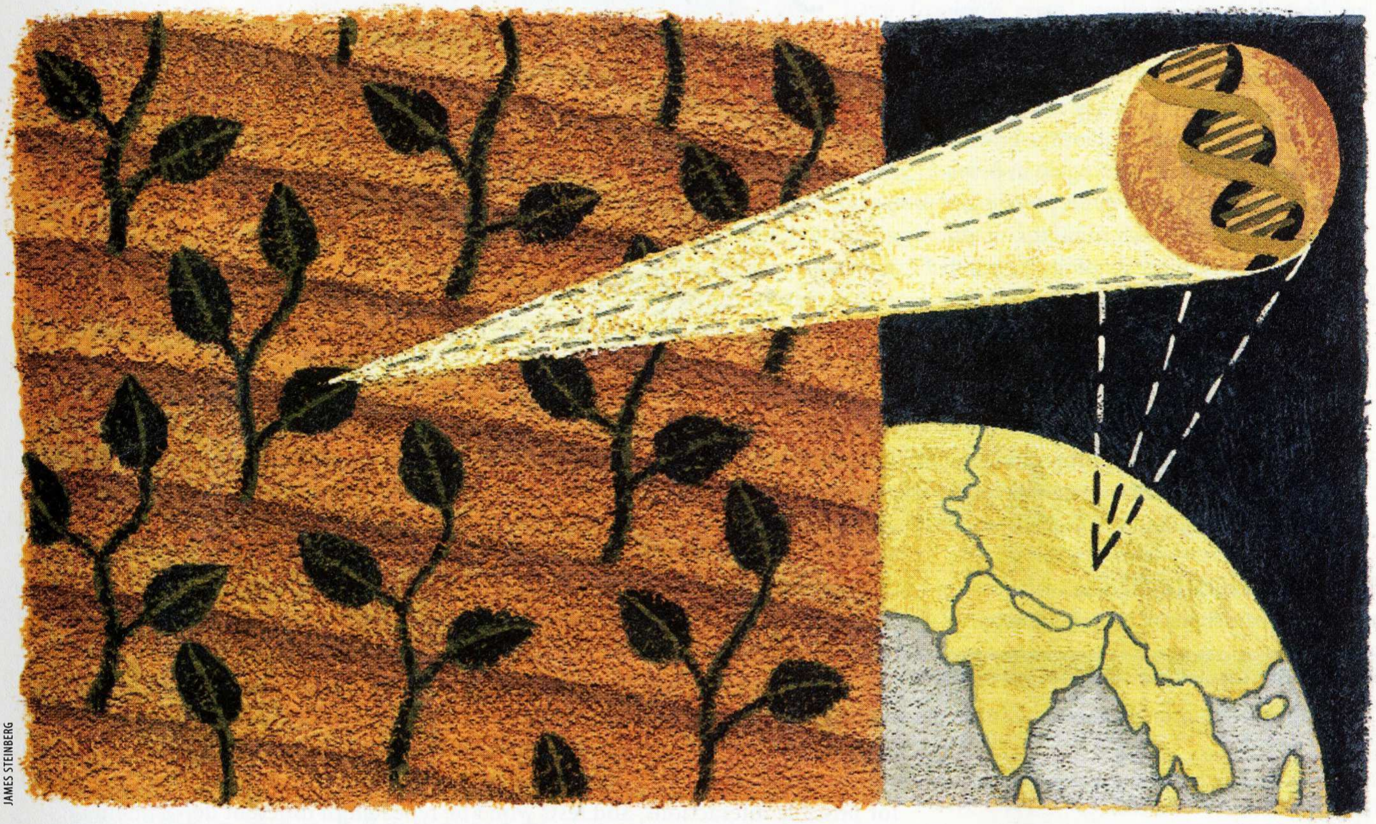
All this recalls what happened back in the 1990s in response to the Clinton administration's absurd restrictions on cryptography. Strong encryption was classified as munitions; exporting crypto was punishable by up to 10 years in prison and up to a $1 million fine. So programmers reduced a powerful encryption algorithm known as RSA to three lines of code and plastered it all over the Web; at least three people even had the lines tattooed onto their bodies. In 1997, the U.S. Department of Commerce decreed that exporting this potent snippet of text required a license. Not that it mattered. Two years later, the administration caved.

Mark Litvack, an attorney representing the MPAA, insists "it has not been our intention to stop debate on the merits and values" of DVD encryption. Instead, he says, his organization is merely trying to wipe out Web sites that are distributing illegal "circumvention devices." Thus, in February, the association wrote a letter to Carnegie Mellon demanding that the university remove Touretzky's Web pages from university servers. The university did not comply.

The movie industry lost its battle over DVDs when it decided it would be neat to let people play DVDs not just on TV sets but on computers. There's no way to keep secret something that's distributed to millions of PC users. Information is power, and computers are machines designed to process and distribute information. Moviemakers are about to learn what the Clinton administration learned with crypto: no matter how you legislate, information wants to be free. TR

INNOVATION

THE FOREFRONT OF EMERGING TECHNOLOGY, R&D AND MARKET TRENDS



JAMES STEINBERG

New Markets for Biotech

Developing countries turn to genetically modified crops

AG BIOTECH | Much of the push to commercialize the first generation of genetically engineered crops has come from large companies in the United States and Western Europe. But the next big producers of biotech crops could very well be nations in the developing world. While battles over genetically modified foods have slowed the technology's progress in Europe and North America, countries such as China and India are now gearing up to commercialize dozens of genetically modified plants in the next few years *(see "Eating the Genes," p. 90)*.

The first such plants hit the market in the mid-1990s, and last year 13 nations allowed them to be grown commercially. Of those, five are in the developing world: Argentina, China, Mexico, South Africa and Uruguay. In fact, China and Argentina now rank among the top four growers, alongside the United States and Canada, in number of hectares planted.

And the adoption of the technology is spreading fastest in some of the world's poorer countries, according to a report by the nonprofit International Service for the Acquisition of Agri-biotech Applications. Between 1999 and 2000 (the most recent year for which data were available), the amount of genetically modified crops planted in the world increased by 4.3 million hectares. While industrial nations—mainly the United States and Canada—still produce three-quarters of the world's biotech crops, 84 percent of the 4.3-million-hectare increase occurred in developing countries. That boost came mainly from Argentina, China and South Africa. Canada, on the other hand, decreased its biotech crop hectarage by 25 percent.

Governments and nonprofit research centers in a number of developing countries are investing in their own genetically modified plants, in the hope of protecting crops from droughts, floods and insects and of getting higher yields out of plants such as rice and cassava that are staples in local diets. "With more than a billion people in India, the government came to the conclusion that it cannot afford to not develop biotech crops," says Claude Fauquet, who heads a training program for international scientists at the Danforth Plant Science Center in St. Louis, MO.

To date, China is the only developing nation to have engineered its own genetically modified crop—insect-resistant cotton—and brought seeds to market. The country has more than 80 state-funded institutions focused on agricultural genetic engineering. Though China's investment pales in comparison to that of the large

agricultural firms, the Chinese government spent roughly $12 million annually on biotech crops in recent years. Similarly, the governments of India and Brazil continue to funnel millions of dollars toward plant biotechnology. All in all, it "dispels the notion that all of the biotech research so far has been going on in developed countries and is all in the private sector," says C. S. Prakash, director of the Center for Plant Biotechnology Research at Tuskegee University in Alabama.

But there are potential roadblocks ahead. Some developing nations, concerned that agricultural exports could be negatively affected by existing or future bans on plant biotech in Europe and elsewhere, are putting the brakes on research. For instance, Thailand, the world's number one exporter of rice, has placed a moratorium on field trials. Other countries have plenty of homegrown resistance to genetic engineering. Mexico, for one, has instituted a field-test moratorium in response to local environmental groups that oppose biotech crops, according to Luis Herrera-Estrella of the Center for Research and Advanced Studies in Irapuato, Mexico. His center is still awaiting government approval of its virus-resistant potato, which is ready to be marketed.

But Prakash, for one, believes the hesitance is only temporary. "When the international hysteria over biotech crops settles down, a lot of these countries will come forward," predicts Prakash. "You're going to see huge increases [in genetically modified crops] in these countries."

—Alexandra Stikeman

New Developments

Biotech crops, in millions of hectares planted

COUNTRY	1999	2000	% CHANGE
United States	28.7	30.3	+6
Canada	4.0	3.0	-25
Argentina	6.7	10.0	+49
China	0.3	0.5	+66
South Africa	0.1	0.2	+100
Mexico	<0.1	<0.1	--
Uruguay	--	<0.1	--

SOURCE: CLIVE JAMES/ISAAA,2000

Digital Hospital

MEDICINE | For a while now, experts in information technology have been chiding hospitals to slim down on the paper patient files and prescription slips and get into better digital shape. While many of the individual pieces of equipment in health care are now computerized, capturing data from these devices and storing it in a centralized system, which then allows for an effective transmission of information to the right people at the right time, lag far behind. One reason that hospitals have been slow to adopt such tools is they're expensive to implement, and managing complex medical information is a difficult job.

Now several big players in health care and data management are bringing their expertise and money to bear on the problem. HealthSouth, one of the largest U.S. providers of health-care services, and Oracle, the giant software supplier, are the latest to announce plans to build an "all-digital hospital." The $100 million facility in suburban Birmingham, AL, will include patient beds with information screens connected to a central database, electronic medical records storage, digital imaging of x-ray film and a wireless communications network that will permit doctors and nurses to update and access patients' medical records using handheld devices. Doctors, for example, could access a patient's history at his or her bedside, calling up x-rays taken two years ago or the results of the blood test taken that morning.

Not all of this technology is new, of course, but what will be novel about the HealthSouth facility is that all of the data will be in compatible electronic systems and stored in a centralized location. In most existing hospitals, medical departments work with customized software or databases that are not compatible with each other, and much of the data is stored on paper. HealthSouth says all of the Birmingham hospital's data will be accessible to every department, so prescriptions can be automatically checked for possible interactions, and tests won't be repeated in different departments.

While others have previously failed to carry off such grand visions of high-tech medicine, the deep pockets of HealthSouth and Oracle could give them a fighting chance. "A digital hospital would require a lot of up-front investment. Electronic transactions would reduce errors and improve patient care efficiency, but it's expensive to install," says Barry Hieb, a physician who is also a research director for Gartner, a technology consulting firm. And, says Hieb, beyond the financials there are technology challenges. "We [Gartner] have a mixed response to the plan. From HealthSouth's perspective, they've done a good job turning existing facilities around, but they don't have a record of automated solutions. And Oracle isn't a clinical-applications vendor. We've seen efforts like this fail before."

But HealthSouth says it's encouraged by earlier trials of digital doctoring. In 1994, the company rolled out a wireless system using handheld devices for automated clinical charting. That first taste of success inspired Richard M. Scrushy, CEO of HealthSouth, to take things farther. "Recent developments in IT made the idea of a digital hospital seem logical and cost effective," says Scrushy.

Not only could electronic information management help eliminate errors, it could also eliminate two to three hours a day that nurses spend charting patient data, and dramatically improve communication between different departments. The bottom line: it could save lives. **—Susan Borden**

Digital devices that could be employed at HealthSouth's hospital include (clockwise from top) a high-tech nurses' station, a patient intercom and a detector that tracks caregivers.

BRIAN WILDER

A square silicone stamp with a microscopic raised pattern is cut out of its mold (right) and then coated with gold (above).

Gold Standard

NANOTECH | As researchers engineer everything from computer chips to drug-discovery tools down to smaller and smaller scales, making these devices is becoming excruciatingly difficult. The principal micromanufacturing technique, photolithography, uses light to etch microscopic features onto a silicon surface; but it's expensive and exacting. One promising alternative is called "soft lithography," a technique that uses flexible rubber stamps to fabricate devices with micro- and nanoscale features.

Until now soft lithography has mainly been used to make tiny devices like microfluidic chambers used for biological research. But Harvard University chemists George Whitesides—soft lithography's pioneer—and Heiko Jacobs have found a new application: transferring nanoscale patterns of electrical charge onto electrically conductive polymers. This advance could mean a cheaper and easier way to manufacture very small data storage and optical devices.

The Harvard scientists accomplished the trick by first building a mold made of silicon, using traditional photolithography methods to carve out the pattern. They then poured rubbery silicone into the mold to make the stamps, which they coated with a thin layer of gold. When the researchers pressed one of these stamps against a polymer film and ran a current through them, the pattern was transferred to the polymer as a series of positive and negative charges. A single mold can churn out multiple stamps, and each can be used repeatedly.

Although the new technique is now just a lab demonstration, potential new applications include encoding data on charge-based storage devices such as "smart cards"—credit-card-sized pieces of plastic used to verify the cardholder's identity—or constructing waveguides for optical telecommunications switches. Says Christopher B. Murray, manager of nanoscale materials and devices at IBM's T. J. Watson Research Center, "This is one more step in a number of beautiful efforts to explore nontraditional patterning technology."

—Erika Jonietz

Mining for Meaning

SOFTWARE | Online newsgroups are popular gathering spots; over the years they've logged millions of opinions on topics ranging from politics to appliances. The largest newsgroup network, Usenet, boasts 500 million messages posted since 1995; unlike postings in chat rooms and online forums, such messages tend to be uncensored—and preserved.

All these postings add up to a trove of public opinion that sociologists, linguists and market researchers would love to analyze; and software projects at IBM and the University of California at Berkeley are beginning to develop the analytical tools they'll need. Unlike Web search engines, which try to find the best matches for any one query, these efforts focus on understanding how communities of individuals interact online, and how their opinions evolve.

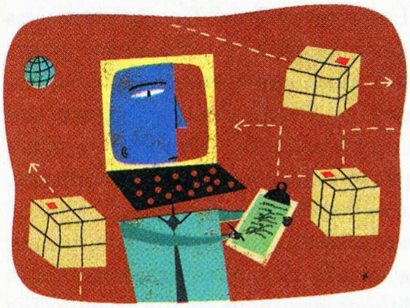
To begin taking on this difficult task, IBM's Babble software depicts conversations as dynamic circular graphs in which icons representing frequent talkers cluster at the center, and less chatty participants move toward the circumference. "People do in fact cluster together when talking, then drift apart," says Thomas Erickson, research analyst at IBM.

But that's only a first step. Beyond charting the chatters lies the task of examining what they're saying. At the University of California, Berkeley, computational linguist Warren Sack's software maps how often words or phrases appear, and how close they are to one another. "In effect you're building a thesaurus of terms that relate directly to the conversation being studied," says Sack. "You can see constellations of conversations, and see which topics are being discussed more than others." One test of this Conversation Map tool helped pinpoint when online participants began thinking of Gulf War syndrome as a "disease" rather than a cluster of symptoms.

Sack and others say they're still years away from a commercial product. When the software is available, though, market researchers just might be the customers: with the right tools, they could turn newsgroups containing millions of opinions into the ultimate focus group.

—Claire Tristram

JAMES YANG



Wireless Stockroom

LOGISTICS | It's a Wal-Mart executive's dream: an inventory system that knows just how many cans of chicken soup are sitting on the shelves and provides a real-time picture of when they arrive from the factory and depart in shoppers' baskets. The first field test of such a system is about to begin.

The likely test bed: a retail warehouse in Tulsa, OK. The technology: tiny versions of the toll-paying "radio tags" found on many car windshields. This October, researchers from MIT's Auto-ID Center will affix these tags to forklift-sized pallets of products. Tag readers on warehouse shelves will log the movements of arriving and departing pallets; this information will be relayed via the Internet to retail headquarters and manufacturers *(see "Beyond the Bar Code,"* TR *March 2001).*

Sponsored by major retailers and manufacturers, the test will extend to tracking individual cans and boxes by next April. This move will be enabled by a new breed of tag costing just pennies each. These new tags, now being prototyped at MIT, will exploit some of the smallest silicon chips ever used.

The potential payoff: a level of inventory monitoring not possible with today's bar code technology, which tracks the movements of product types, not individual items. Bar codes save businesses billions every year; wireless alternatives may save billions more by boosting efficiency and reducing theft, oversupplies and shortages, says David Weil, a professor of economics at Boston University. —Erika Jonietz

JAMES YANG

Attractive Shapes

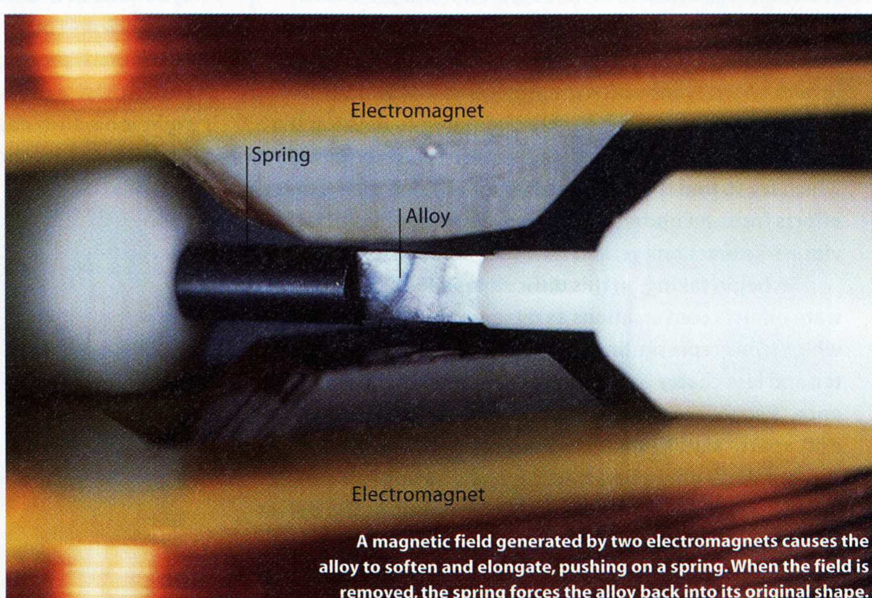
Magnetically controlled metal could yield better machine parts

MATERIALS | Materials scientists have long played with "shape memory alloys," metals that shift between one shape and another when heated or cooled to just the right temperature. But so far, real-world applications have been limited, because controlling the alloy's shape with temperature is often difficult and inefficient. Now, researchers have found a way to accomplish the same shape-memory tricks using magnets rather than temperature—an advance that could make possible efficient, less clunky moving parts for machine components in aircraft, automobiles or even robots.

Materials scientists Bob O'Handley of MIT and Kari Ullakko from the Helsinki University of Technology in Finland reasoned that an alloy of nickel, manganese and gallium might respond to a magnetic field with a change of shape. When the researchers expose a sample of the new alloy to a magnetic field about two or three times stronger than that generated by a refrigerator magnet, the material becomes rubbery and expands. When the researchers remove the field, a spring pushing on the alloy causes it to revert to its original shape. By alternating the magnetic field at high speed, the researchers can repeat the cycle several thousand times per minute. "It sort of looks like a heart beating very quickly," says O'Handley.

Adding magnetic control, researchers believe, will make shape memory alloys much more practical to use. "There's a great deal of promise in these [magnetically controlled] materials," says the University of Minnesota's Thomas Shield, who also studies shape memory alloys. O'Handley, for example, envisions using the alloy to make lightweight mechanical parts in airplane wing flaps. A lump of the new material wrapped in a magnetic coil could raise and lower a flap on cue, replacing today's heavy hydraulic systems that require a central pump and multiple oil lines running to the flaps.

O'Handley and his crew have also partnered with two engineering firms in the Boston area—Midé Technology and ACX—that manufacture valves and pumps for automotive and aerospace applications, among other uses. The researchers aim to have a working prototype of a generic pump ready before the end of this year. The MIT scientists are also working with four other universities to make a magnetic shape memory material that combines the metal alloy with a polymer. If it works, it could lead to an even lighter and cheaper "beating heart." **—Alexandra Stikeman**

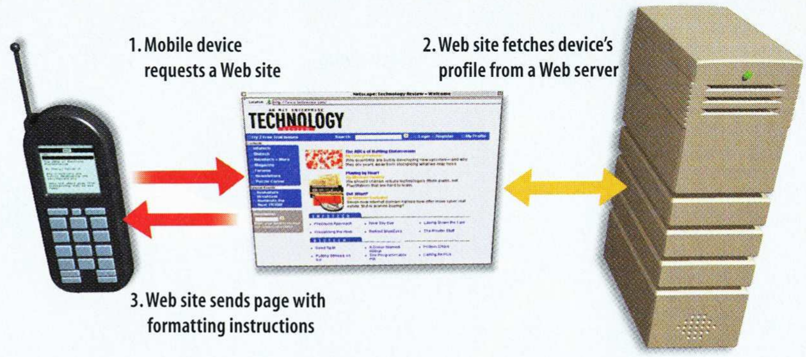


A magnetic field generated by two electromagnets causes the alloy to soften and elongate, pushing on a spring. When the field is removed, the spring forces the alloy back into its original shape.

FURNALD/GRAY

Handy Rules

New standards could ease access to the wireless Web



WIRELESS | Try accessing the wireless Web with your cell phone, pager or handheld computer and you'll quickly realize the technology does not live up to its promise *(see "Mobile Web vs. Reality,"* TR *June 2001).* Most Internet sites are designed for PCs, not the tiny display, limited keyboard, and software specifications of a handheld. This is why you have to scroll side-to-side to see a Web page and why you frequently get error messages telling you to update your browser. However, new Web standards that could be implemented within the next two years will give your device the ability to request any Web page and have it automatically tailored to meet the device's needs. Leading the way is the Cambridge, MA-based World Wide Web Consortium, a group that represents more than 500 industry organizations and is charged with determining technical guidelines for Web use *(see "The Web's Unelected Government,"* TR *November/December 1998).*

The current standards for mobile devices allow Web-enabled handhelds to receive information over the Internet. But the standards don't guarantee that a Web site will be formatted to suit a particular device's capabilities. In addition, pages often contain bits of code easily read by PCs but indecipherable by mobile devices.

The consortium hopes to solve these problems with new standards that would allow a Web site to obtain technical details about the handhelds requesting its content and respond with appropriately formatted pages. Each request would contain a "pointer" that would tell the site to fetch a profile of the device's capabilities from a remote server. In turn, the Web site would send its page back to the device with a "note" describing how the page should look. That way, elaborately designed sites would automatically be pared down for your cell phone's tiny screen.

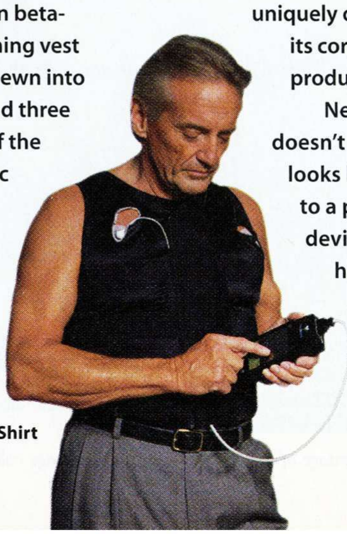
According to Ken Dulaney, vice president for mobile computing at Gartner, a technology consulting firm, "The future of [mobile devices] is heavily dependent on this key piece of technology."

—Alexandra Stikeman

Clothed in Health

MEDICINE | For millions of Americans with chronic medical conditions, careful day-to-day health monitoring can help avert catastrophe. Home health gauges abound, but they take readings only at discrete points in time and require a patient's active participation—answering a computer questionnaire, for example. The ideal monitor, however, would record data constantly, and patients wouldn't even notice it's there. This summer, a few firms take that next step, commercializing wearable health sensors. "There's no question we're going remote, and we're going wireless," says Credit Suisse First Boston's Robert Hopkins.

In March, VivoMetrics of Ventura, CA, began beta-testing its LifeShirt, which looks like a sleek fishing vest and records more than 40 health parameters. Sewn into the vest are electrodes for heart monitoring and three conductive bands that gauge the movement of the heart and lungs from changes in their magnetic fields. The sensors measure both vital signs and indicators of psychological state, like sighing. A belt-mounted device records the data, which can be sent over the Internet to a doctor—who might notice dangerous spikes in heart rate, say, and adjust medications accordingly.



VivoMetrics' LifeShirt

VivoMetrics anticipates its first customers will be drug companies trying to gather better data in clinical trials. "There's the possibility we'll be able to detect subtle changes that are not picked up...in the doctor's office," says VivoMetrics vice president for health care Bill Cary. U.S. Food and Drug Administration approval should come this summer, Cary says.

Still, it's hard to imagine millions of people wearing fishing vests to the office. Addison, TX-based Sensatex believes that its fabric—woven from optical and electrical fibers—will allow the integration of electronic components into more conventional clothing. Sensatex concentrates uniquely on production of the fabric, but it expects that its corporate partners will introduce monitoring products using its technology by next summer.

Nexan of Alpharetta, GA, on the other hand, doesn't bother with wiring clothes. Its sensor—which looks like an elaborately bent paper clip—adheres to a patient's chest and radios data to a storage device up to 15 meters away, which can be hooked into the Internet. Electrodes in the sensor measure respiration and contraction of the heart. Nexan hopes its system will aid in the clinical evaluation of patients with congestive heart failure and looks for FDA approval this summer. —Larry Hardesty

The ABC's of Safety: Air bags. Buckle up. Children in back. *At maximum output.

ENGINEERED TO BE ALMOST PSYCHIC.

Introducing a car so technologically advanced, it can sense trouble and begin to adjust for it before the driver even notices that there's a problem. It's the 6-cylinder 212-horsepower Outback VDC from Subaru. The VDC stands for Vehicle Dynamics Control, a highly intelligent stability system that rivals those found in vehicles costing thousands more.

Using a sophisticated series of sensors, VDC can help prevent loss of control due to oversteer, understeer, wheel spin or vehicle drift. The instant a difference is detected between the driver's intended direction of travel and the path the car is actually taking, VDC takes corrective action. Momentary brake pressure may be applied to individual wheels. The All-Wheel Drive system may redistribute the amount of power between the wheels. Even the engine's output may be momentarily reduced. Before the driver even realizes that loss of control is impending, any or all of these measures may be applied automatically to help restore directional stability. It's almost as if the car has a sixth sense.

In fact, in every sense the Outback VDC is a remarkable vehicle. It even features a state-of-the-art 200-watt* sound system built exclusively for Subaru by McIntosh®. With 11 speakers placed in 7 strategic locations, the audio quality has been specifically tuned to the car's unique acoustics.

The Outback VDC from Subaru. Truly a phenomenon in the world of automotive engineering. To find out more, visit us at **www.subaru.com.**

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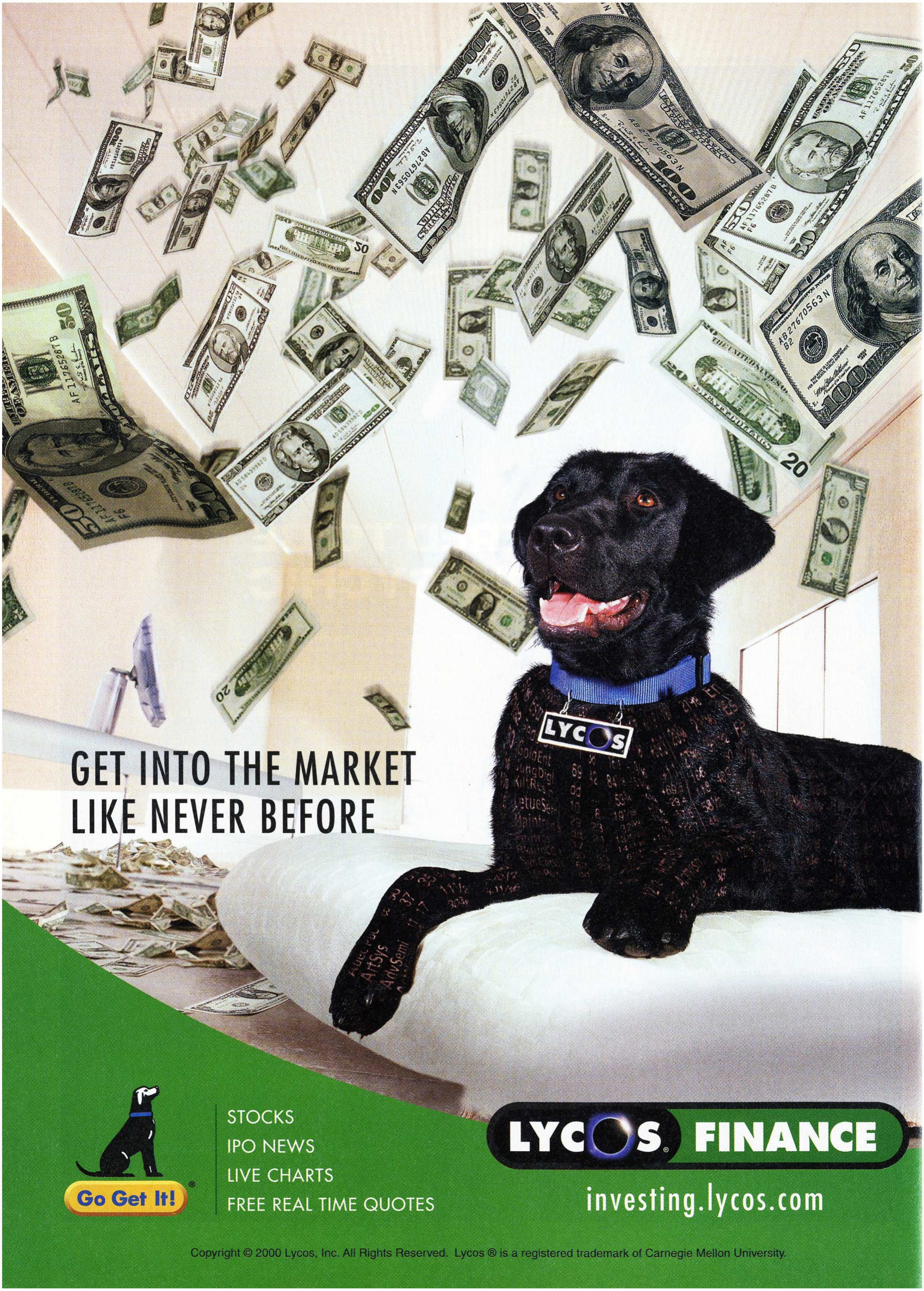
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UPSTREAM

SPOTLIGHT ON A HOT TECHNOLOGY TO WATCH

CARNEGIE MELLON INFORMEDIA PROJECT

At Carnegie Mellon's Informedia project, researchers are working on ways to automatically search large video databases by a combination of methods. In the above shots, the red boxes identify words, while the green boxes identify faces. Video can then be searched for, say, "Tim Russert," or for his face.

Video Searching

Better methods for finding a face in the crowd

EVERY DAY, A RIVER OF VIDEO floods the airwaves, courses through cables and streams over the Internet. Add to that all the films ever made, plus all of the video material created for private use, and you've got an ocean of light and sound. But how can you ever find and retrieve a particular video clip?

With text documents, you can type in a query, and a piece of software finds the matching text strings. Searching video is much tougher. Unless someone has gone back and somehow marked the video data, it's now nearly impossible to find a specific image. A content provider like CNN has more than a hundred thousand hours of tape in its video archive—far too much for any human to view and annotate manually. Now a small but growing number of labs are searching for novel ways to better navigate the video glut.

These are still early days for video indexing and retrieval. A few existing Web search engines like AltaVista can find some video clips, but they only return those that are on Web pages with text that can be searched by keywords. Likewise, San Mateo, CA-based Virage has developed a search engine for ABCNews.com that allows the transcript of a broadcast to be searched; the search, however, is also by keywords, and the video is played from the point at which the specified word occurred. None of these systems provides direct image searches—in other words, a video answer to the command "give me all the clips of an astronaut outside the space station Mir."

Video-search and database tools that directly find images can be far more powerful than keyword searches. At Columbia University, a team led by Shih-Fu Chang is developing software that can search a video for particular features in the images—such as shape, color and motion. For example, you could select a static image from a catalogue and have the software find close matches in the video frames. Or you could make a simple sketch of a blob, with a few arrows to show how it moves, and the system finds video segments that match these features. For instance, you could roughly sketch the shape of the Mir space station and a human figure moving outside it.

This kind of direct image query could be especially useful for large databases of video records. Chang's group has been researching ways to extract information from medical-exam videos. Every year at Columbia-Presbyterian Medical Center, "ten thousand echocardiograms [ultrasound movies of the heart] are performed," he explains. "Each is about a half-hour long, and they get put into a tape library." A cardiologist then has to look up the ultrasound to make a diagnosis, wasting a lot of time fast-forwarding and rewinding through the tape. Much better would be an automatic way of detecting signs of heart ailment in the video stream. Chang's software first parses the ultrasound video into segments by looking for sharp changes in image content—when the view on the ultrasound display is switched to another angle, for instance. Each segment is then processed by a "view recognizer" that matches the images to known images of abnormal events and flags any suspected heart conditions.

At Carnegie Mellon University, researchers are creating a digital library that combines natural-language processing, speech recognition and image analysis. "The integration of these different technologies is the key," says Howard D. Wactlar, director of the Informedia Digital Video Library Project at Carnegie Mellon. A prototype captures news broadcasts from around the world and stores them, along with summaries or storyboards. Someone can then type in a question, or just utter the question aloud: "Tell me about oxygen problems on the Russian space station Mir." All the relevant news clips are displayed as frame icons you can click on. The system is also incorporating face recognition to make it possible to call up all the clips of a particular person *(see graphic above)*.

It will be some time before direct video searches become routine. But if today's research pays off, finding a video needle in the immense multimedia haystack will be no more difficult than typing in a few words—or maybe sketching out a simple image. **—David Voss**

Patent Pollution

It is not a perfect world. Tankers spill oil. Innocent people land in jail. Bad calls cost the home team a championship. And as almost anyone in the intellectual-property game will tell you, the U.S. Patent and Trademark Office continues to grant patents that are, well, patently invalid. I'm talking about patents for things that have either already been invented or are so straightforward and apparent they don't meet the patent's law requirements for being novel and nonobvious.

For years, people have griped about these bogus patent claims. Rightfully so, since firms shell out millions in needless licensing fees as a result. And the patent office has long promised to do better. But now two Web-based ventures, IP.com and BountyQuest, are taking their own steps to rein in bad patents—either by stopping them before they are granted or by knocking them out after the fact. What makes these startups really interesting is that they are attracting support across a broad spectrum of intellectual-property players—from patent system boosters to open-source programmers. In the polarized IP field, that is no small feat.

The nub of the problem is that a U.S. patent affords the holder a 20-year monopoly on an idea, whether it's granted on valid grounds or not: that is, unless the patent office is convinced to reexamine its decision, or the patent is invalidated in court. Both procedures take some effort, however. And the average patent case that goes to trial now costs millions, with unpredictable verdicts. The result: even when someone wielding a blatantly invalid patent demands royalties, your lawyer will often advise you to pony up rather than fight.

Of course, it isn't supposed to work that way. If a concept is obvious to practitioners in a given field or has previously been published in almost any fashion, that should invalidate the application. Practically speaking, however, it's a tall order for the U.S. Patent and Trademark Office to scour the universe of publications to determine whether your software code or concept has already surfaced. So mistakes are made—eroding confidence in the system and feeding the problem by encouraging firms to apply for dubious and overly broad patents of their own.

Easing this patent pollution is where the new Web-based firms come in. IP.com, of West Henrietta, NY, offers a low-cost registration system that allows inventors to place their work in the public domain and prevent others from patenting it. A document submitted to IP.com becomes part of a database that both the U.S. and European Patent Offices have promised to search before issuing patents. And while it can only be used defensively—to protect against bogus claims and not as a means of collecting royalties—an impressive list of firms, from Abbott Laboratories to United Technologies, has begun using IP.com to guard against patent infringement lawsuits.

The standard fee for this insurance: just $109. However, IP.com also provides a similar service to open-source programmers for less than $20. Open-sourcers can thus gleefully thwart the excesses of a patent system they decry, preserving their work in a form protected from proprietary claims.

Tom Colson, CEO of IP.com, says the stew of questionable patents reminds him of his work as a young lawyer on toxic-contamination cases. Cleanup campaigns, he notes, typically involve two separate efforts: stopping pollution on the one hand, and clearing up the existing mess on the other. The environmental analogy is apt.

If IP.com targets patent pollution, Boston-based BountyQuest is out to remediate the other half of the trouble: patents of questionable validity that may already be wreaking havoc. Taking its cue from bounty hunters who track fugitive criminals for a fee, BountyQuest posts rewards of $10,000 and up that have been offered by threatened firms for "fugitive information" that can help bust invalid patents. Such bounties are a small price for threatened firms to pay for proof of prior art that will force bogus claimants to back off.

Two Web-based ventures are wielding the power of the Internet to try and clean up the patent system.

In its most highly publicized bounty to date, BountyQuest investor Tim O'Reilly, who heads computer publisher O'Reilly & Associates, posted a $10,000 reward for infor-mation that would invalidate Amazon.com's "1-Click" online shopping patent. While the case drags on with unclear results, BountyQuest drew 25 submissions and ended up splitting the reward among three bounty hunters who provided information on various clicking patents related to making online purchases. Since its launch earlier this year, BountyQuest has paid $60,000 in rewards. At the time of this writing, it had roughly half a dozen open bounties posted on its Web site (www.bountyquest.com), looking to bust patents involving everything from prepaid cellular calls to a drug treatment for osteoporosis.

With thousands of patents issuing weekly, we can't expect these two ventures to solve the problem of invalid patents. But by drawing their strength from the distributive power of the Web rather than counting on an infallible patent system, they offer hope. TR

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The real energy crisis may be happening on the nation's aging power grid. Getting electricity from here to there over high-power transmission lines is becoming more unpredictable and difficult. Engineers in New York may have the solution.

A Smarter POWER GRID

BY PETER FAIRLEY PHOTOGRAPHS BY JAN STALLER

The Marcy substation in upstate New York switches electricity flowing down from Canada's hydroelectric plants from 765,000 volts to 345,000 volts, a form in which it can be more easily transmitted to New York City, 300 kilometers away. "Power electronics" help to improve electricity delivery over the New York-bound transmission lines (above).

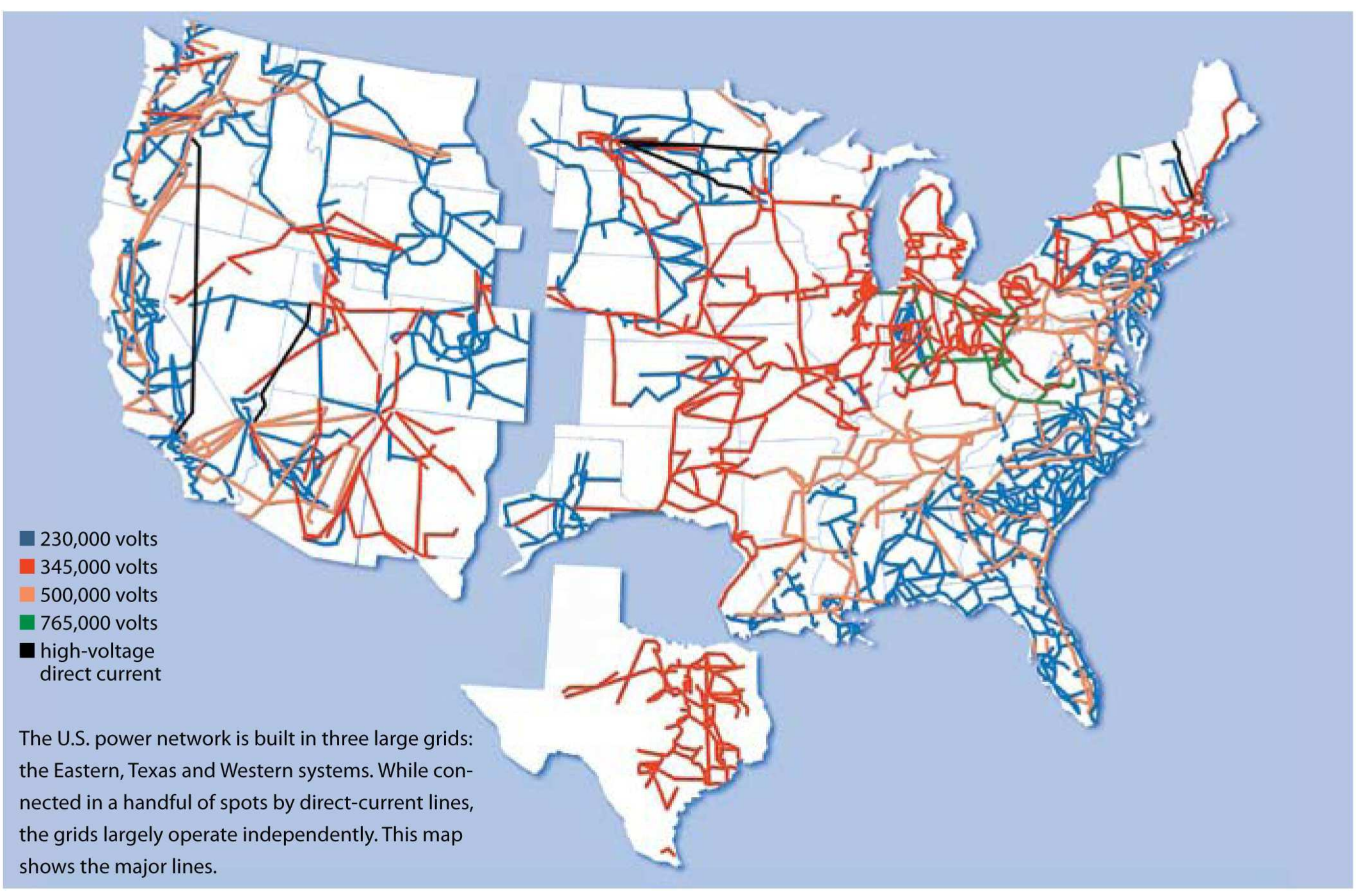
Thousands of megawatts of cheap, clean hydroelectricity from Canada are continuously rushing into the New York Power Authority's sprawling substation in Marcy, NY—enough juice to light up 40 World Trade Centers. For almost a half-century, the Marcy facility, located just a few miles from the remote Adirondack National Park in upstate New York, has transformed this torrent of electricity from a blistering 765,000 volts to the slightly more manageable 345,000 volts used by the overhead transmission cables that feed power-hungry Manhattan 300 kilometers to the southeast.

But the real action at Marcy these days takes place in a nondescript metal building, easily overlooked amidst the 40-meter-high towers supporting the mass of transmission cables. Here, European engineering giant Siemens has just installed the world's most sophisticated high-power switch. If things get really hot this summer, the ability of the specialized chips inside the device to route electricity exactly where it's needed just might save New York City's cool.

The novel Siemens switch that holds these electric-power processors stands four meters high, and its silicon valves juggle electrons at power levels that would blow your cell phone or PC to bits. But just as silicon chips in your cell phone process electromagnetic signals to transmit information, Siemens's brawny electrical-power processor can filter and manipulate the alternating current flowing through the Marcy station. The immediate goal is to stabilize central New York's stressed electric grid, making it safe to transmit more energy through the lines. Then next summer, with a few more patch cables and a hefty new fuse added to the system, the power switch should be ready for an even more sophisticated trick: nimbly swapping electricity between high-power transmission cables—a feat never before attempted.

If it succeeds, the electricity swap will be like a coronary bypass for a critical artery in the increasingly sclerotic national power grid. In many ways, the energy "crisis" that is gripping California and threatening the rest of North America is as much about getting electricity to flow where you need it—when you need it—as it is about a lack of energy. The problem is that the existing network of high-power transmission lines, the interconnected web of electricity that keeps the continent charged (power grids in northern Mexico and in Canada are closely intertwined with those in the United States), was built in the middle of the last century and was never meant to handle the complexity and congestion of today's ever growing energy demands and changing markets.

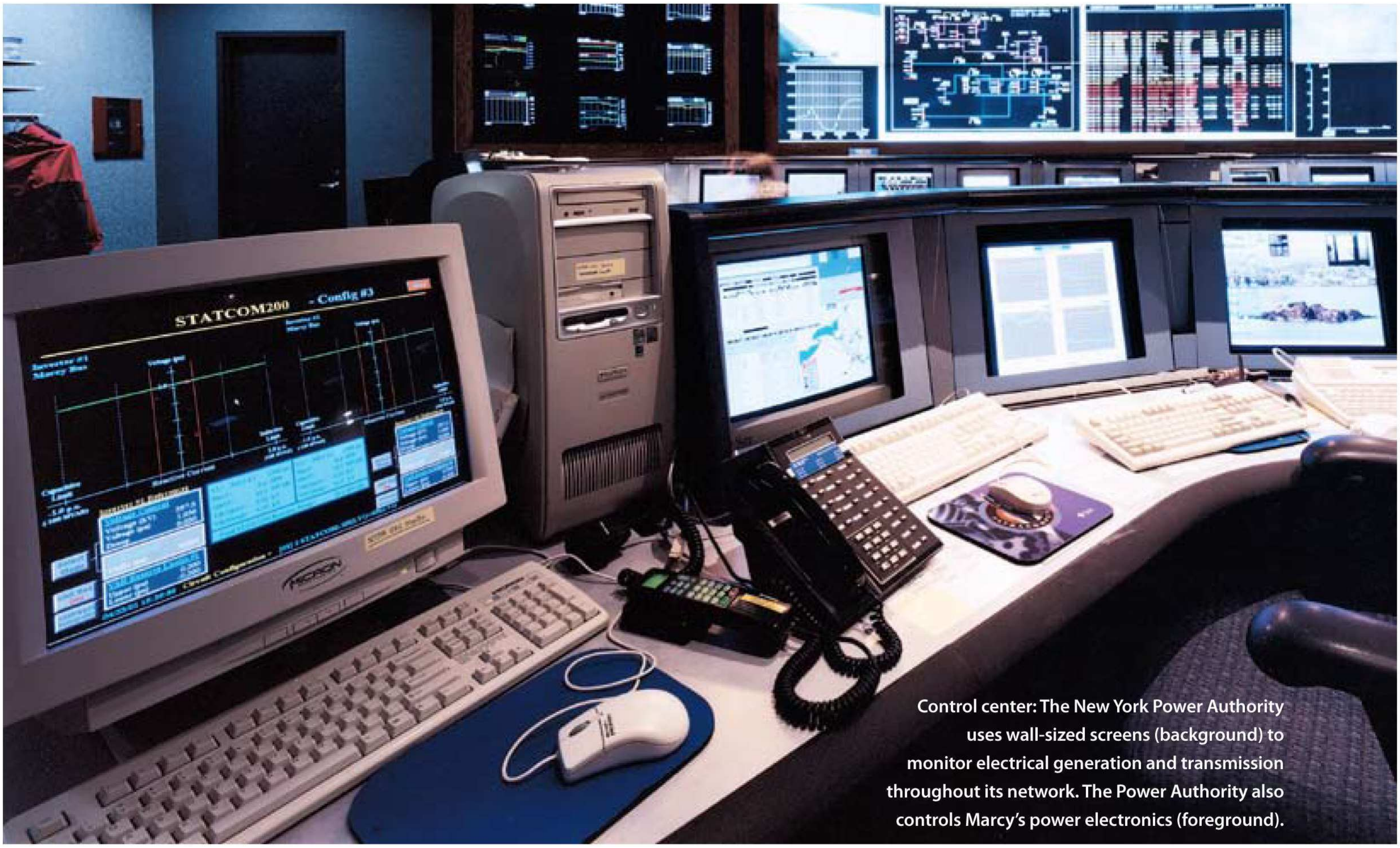
U.S. Power Grid: The Electricity Lifeline



The U.S. power network is built in three large grids: the Eastern, Texas and Western systems. While connected in a handful of spots by direct-current lines, the grids largely operate independently. This map shows the major lines.

ILLUSTRATION: BETSY HAYES; SOURCE: POWERWORLD

Stacking the odds: A technician at the Marcy substation works on the equipment used to control power distribution.



Control center: The New York Power Authority uses wall-sized screens (background) to monitor electrical generation and transmission throughout its network. The Power Authority also controls Marcy's power electronics (foreground).

In light of this situation, the North American Electric Reliability Council, the industry's voluntary watchdog group, is telling just about anyone who will listen that the system is at risk. "The question is not whether, but when, the next major failure of the grid will occur," wrote the group's general counsel David Cook in a recent entreaty to the U.S. Department of Energy in Washington, DC.

WHITE ELEPHANT

The U.S. power grid has been called the largest machine ever built by man. In fact it's really three loosely interconnected grids: one in Texas, and two more splitting the bulk of the country roughly along the Continental divide *(see "The Electricity Lifeline," p. 42)*. These systems are far from orderly; each grid is composed of a tangle of transmission lines operated by a hodgepodge of owners, from sprawling federal power authorities to regulated utilities to market-savvy conglomerates. An equally variable set of state, regional and federal regulators governs aspects of this mosaic, deciding how much power can enter the grids and flow over each set of lines.

Despite its structural and regulatory complexity, though, the power grid operates on a startlingly simple basis: electricity flows from where it's produced to its destination through the path of least resistance. That worked fine in the days when monolithic electrical monopolies strategically sited their power plants on the grid, with the path of least resistance leading straight to their own customers and no one else's. But those days are long gone. Deregulation of the electrical industry in the 1990s opened the grid to anyone and everyone who had electricity to sell. Dozens of brokers building new power plants and old utility giants with a fresh entrepreneurial bent now want to supply whoever offers the highest price for their power, wherever he or she may be. And that's where the physics of the existing grid comes up dangerously short.

The changing nature of the electrical industry dictates complex crisscrossing flows of electricity and the need to send more and more power over long distances. "We're trying to use [the electric grid] for a lot of longer-distance power transfers, and it's just stretching to the limit," warns Thomas Overbye, a power systems expert at the University of Illinois at Urbana-Champaign. Indeed, there already have been signs of troubles. In the blistering summer of 1996, the western U.S. electric grid snapped twice as swollen lines feeding hydroelectric power from the Pacific Northwest to California overloaded and shorted out. The result? Blackouts in 11 western states, Alberta, British Columbia, and Baja California. To avoid a repeat of that crisis, grid operators in California must restrict flows to the state, a fact that is greatly exacerbating its ongoing power crunch.

If today's situation sounds to you like a recipe for even worse power meltdowns, get your candles ready—because while hundreds of planned new power plants around the country will increase the amount of available electricity, utilities are investing next to nothing in additional transmission lines to get the juice to where it's needed. It used to be that the big utilities owned and maintained their share of the grid. But deregulation has orphaned the transmission business, uncoupling the lines that deliver electricity from revenue-producing power plants. And owning transmission lines is a business few want any part of. If you think building new power plants is unpopular, try running high-power transmission lines through someone's backyard. (Do electromagnetic radiation and contentious town-hall meetings come to mind?)

Smooth sailing: Specialized transformers at the Marcy substation smooth out the wave of alternating current coming out of silicon power valves.

Just 13,500 kilometers of high-voltage transmission additions are planned throughout North America over the next decade—a 4.2 percent increase—of which only a fraction are likely to get built. Meanwhile, the U.S. Department of Energy estimates that generating capacity in the United States alone will grow more than 20 percent over that period.

Enter power electronics—like the ones being installed at Marcy. If you can't build enough new transmission lines to keep pace with the growing power demand, it becomes imperative to build a more efficient way to direct electricity over long distances. In the same way that telecommunications companies have created a complex yet seamless network controlled by automated electronic switches that zap phone calls and data around the world, the engineering giants that build transmission systems are attempting to reenergize the grid electronically.

That transformation has already begun, as a handful of groups, like the Tennessee Valley Authority, install electronic power systems to prop up the far edges of their distribution networks, which are especially vulnerable to energy fluctuations. But even more sophisticated systems, like the one being installed at Marcy, could take electronic control to the heart of the grid. Not only could these power processors make the network more efficient, they could enable a new level of control over the transmission grid, allowing power cables to operate like toll roads and providing revenue sources that could attract the private capital badly needed to upgrade and maintain the systems.

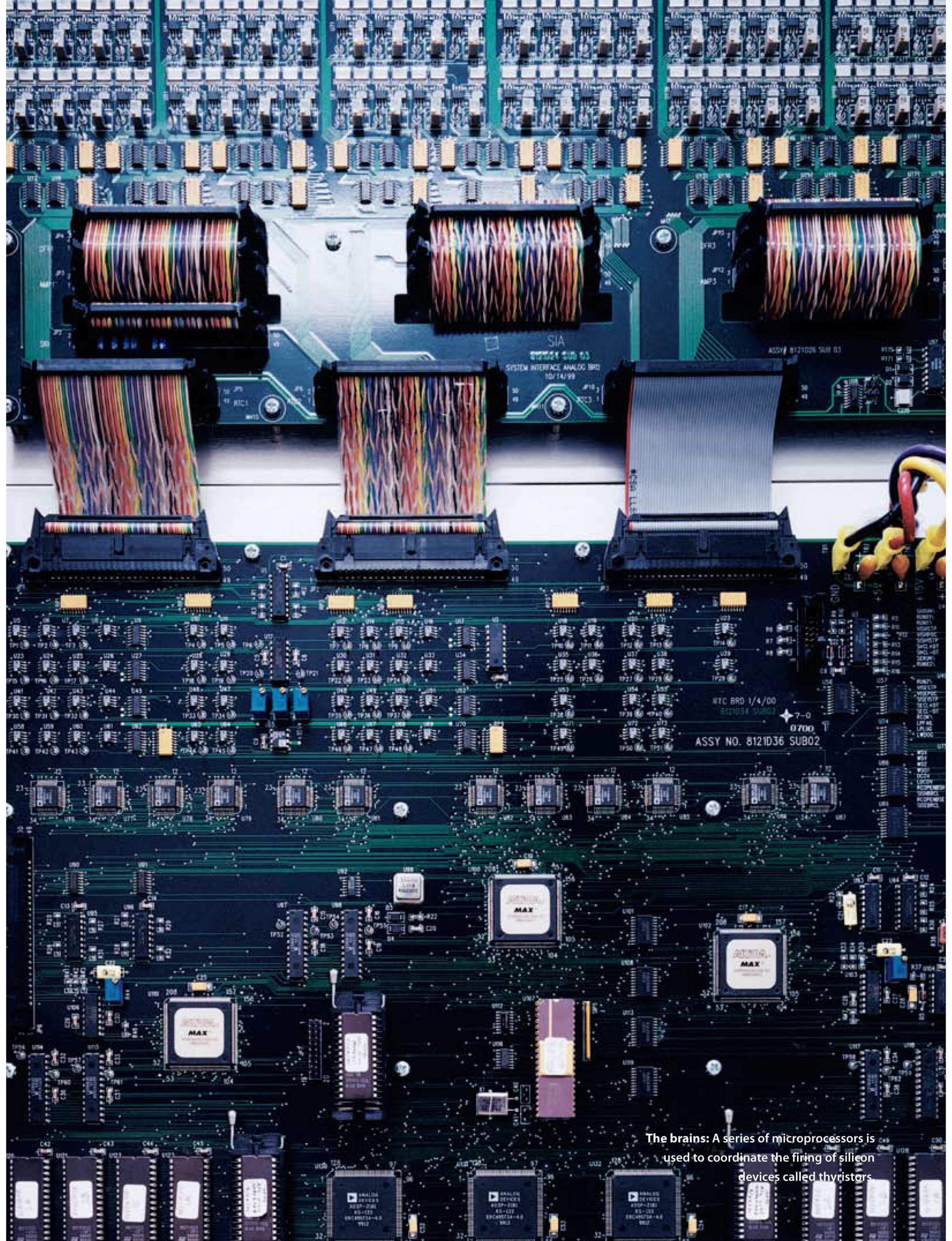
For those wanting to make that scenario happen, the Marcy substation is a critical experiment, a high-stakes test of the technology on a system that tens of millions of people depend on for electricity. Marcy may be 300 kilometers from the bright lights of Broadway, but if power electronics can make it there, it can make it anywhere.

POWER CHIPS

Electronic control over the grid has been a long time coming. The core problem has always been to switch high levels of electricity—and to do it fast enough. The potential solution dates back to the late 1950s, when General Electric pioneered the thyristor, a cousin of the transistor.

Like transistors, thyristors turn the flow of electrons through an integrated circuit on or off. Thyristors are more efficient for handling big power loads because, unlike transistors, once turned on they stay on—allowing energy to flow with little resistance. But the solid-state "latch" that's the key to this ability also renders the thyristor thousands of times slower to switch than the transistor, limiting its ability to regulate the high-speed action of the electric grid. That began to change in the 1980s with the arrival of a speedy hybrid device called the gate turn-off thyristor, which employs its own dedicated circuit of transistors to electronically open and close the thyristor's latch. These and other advances have enabled power electronics to be used increasingly in consumer applications such as smoothing out the flow of juice from small-scale power generators *(see "Power to the People," TR May 2001)*.

Now, thanks to the Electric Power Research Institute, a utility-funded R&D consortium in Palo Alto, CA, and demonstrations with utilities and large engineering firms such as Siemens, ABB and Mitsubishi Electric, power electronics is finally ready for heavy lifting in the transmission grid. The first payoff of these



The brains: A series of microprocessors is used to coordinate the firing of silicon devices called thyristors.

systems will be to make the grid less vulnerable to voltage sags and surges, as well as to noise in the power signal.

While the electric grid was originally interconnected to increase reliability and reduce cost, that's turned out to be a mixed blessing. Interconnection means the most expensive generators can be kept off if others—even several hundred or several thousand kilometers away—can fill the need more cost-effectively. The bad news is that the grid can also transmit disturbances, making the whole system harder to control. Fluctuations can work their way around the grid like the wave among fans at a football stadium. And just as the wave works better at a crowded arena, an electric disturbance becomes more pronounced at higher power levels and with increased power transfers. "Unfortunately, by the nature of the physics involved, the higher the power flows the more dynamically unstable you become," says Karl Stahlkopf, vice president of power delivery at the Electric Power Research Institute.

Because high-power transmission is so unstable, operators must often limit a line's load to as little as 60 percent of its ultimate thermal capacity (the point at which the wire overheats, sags into trees or onto the ground, and shorts out). Power electronics is beginning to reclaim this lost capacity using programmable processors that can patch over a surge or sag within a small fraction of a second. That's a big advance over conventional grid controls, which can be as slow as manually adjusting a transformer or as unsophisticated as automatic breakers that sense a disturbance and "trip" a transmission cable off line, sending a tsunami of power surging through neighboring circuits.

The first of these power processors were installed in 1995 by the Electric Power Research Institute, Siemens and the Tennessee Valley Authority in northeast Tennessee. By smoothing out the flow, electronics eliminated the need for a new power line, saving at least $14 million. It was a modest but encouraging first step, and Siemens and ABB have recently sold three more commercial power processors to Texas utility Central and South West. Meanwhile, Mitsubishi Electric recently installed one in Vermont and is engineering the first of four units destined for San Diego Gas and Electric. By making it safe to draw hundreds of extra megawatts from distant sources over existing transmission lines, San Diego's devices will help overcome the shortage of local power generation that has left power companies throughout California vulnerable to outages and price swings.

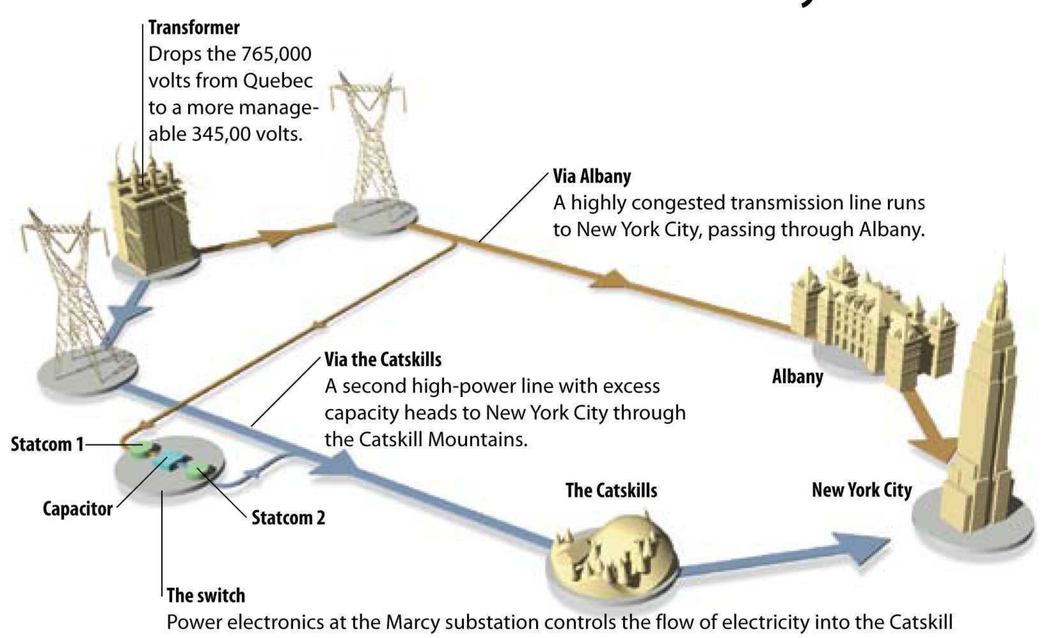
POWER PLAY

Impressive, maybe, but these systems are still more or less Band-Aids. The installation at Marcy represents the first attempt at major surgery for the grid. The diseased arteries are the two 345,000-volt transmission lines that run south from Marcy to New York City: one skirts Albany and then chases the Hudson; the other traverses the Catskill Mountains to the west before it heads for Manhattan. With a push of a button, a series of breakers at Marcy will reconfigure the station's circuits to pump electricity from one line to the other as needed *(see "The Electronics Solution at Marcy," below)*. "We will have the ability to actually alter the flow of energy—take it off of one line, put it on another line, particularly if that line is starting to get into an overload condition," says Gerald LaRose, who runs the Power Authority's mission control center at Marcy.

LaRose is particularly eager to relieve the line connecting Marcy to New York City via Albany. The operators know it as Marcy-South, and it is easily the state's most congested high-power transmission line, stuffed to capacity 25 percent of the time and skating within 100 megawatts of overload for much of the rest. The line is obsessively monitored, and each time it approaches critical, the New York Independent System Operator, the agency that manages the state's grid, must cease adding power to it—indeed, to all of the highly connected circuits running throughout central New York. Even those lines with spare capacity must be squelched, since some fraction of any additional power could reach the stressed Marcy-South line and push it over the edge.

On a hot day when power demand is peaking, squelching electricity flowing from upstate could spell trouble in New York City. At best, the city must fire up expensive and polluting gas- or oil-fired power plants to make up for the constrained flow of hydropower from Quebec. At worst, neighborhoods could be plunged into darkness. While this worst-case scenario has yet to happen, experts agree that New York City is becoming ever more vulnerable.

The Electronics Solution at Marcy



The switch
Power electronics at the Marcy substation controls the flow of electricity into the Catskill and Albany lines. A pair of devices called "statcom" reshape the alternating current in each line, which makes it possible to "pump" power from one line to the other. Electricity is stored and released by the capacitor.

SLIM FILMS

Cooling Down in Motown

A gritty section of Detroit surrounds one of the city's oldest electric power stations. But the technology that Detroit Edison is installing at the Frisbie substation is pure 21st century—underground superconducting cables that can transmit immense currents of electricity with near perfect efficiency.

While increasing energy demands are putting more and more stress on the nation's long-distance power transmission network, cities are suffering their own version of electric gridlock; in many locations, underground transmission lines are fast reaching capacity and are literally burning up. Superconducting cables, like the ones being installed in Detroit, could safely triple the power moving through existing conduits, avoiding the need to dig up the streets—even making room for fiber-optic communications lines.

The Frisbie demonstration marks a milestone in electricity know-how—one of the first commercial applications of high-temperature superconductors. These ceramics, first fashioned by IBM researchers in 1986, now transmit alternating currents with nearly zero resistance at temperatures as high as -139 °C (the materials can be cheaply cooled to that temperature using liquid nitrogen). In contrast, conventional copper cables dissipate as much as 10 percent of the power they carry because of resistance; that lost power escapes as heat, which limits just how much juice can flow before the cable melts.

American Superconductor, the firm making the materials being tested in Detroit, has been trying to find real-life uses for the ceramics since it was founded in 1987 by MIT materials scientists Greg Yurek and John Vander Sande. Their trick is to fabricate the superconductor as flexible conductive tapes. Pirelli Cables and Systems, the world's largest producer of power cables, wraps the tape with insulation and a protective sheath on the outside and a channel up the middle for the liquid-nitrogen coolant, which keeps the tape in superconducting mode.

JEFF AMBERG

Cool cable: The high-temperature superconducting cable made by Pirelli wraps the flexible superconducting ceramic (silver strips) from American Superconductor with a number of protective layers. Through the middle of the cable runs a channel that can be filled with liquid nitrogen to keep the superconducting material cooled.

Surrounded by shuttered buildings and empty lots, the Frisbie station has plenty of spare capacity—meaning its 13,500 customers won't be left in the dark if the superconducting cables fail. But Detroit Edison is already looking at using the technology to replace overloaded conventional cables serving busier sections of the city.

And Pirelli R&D manager for superconductivity Marco Nassi says success in Detroit should lead to commercialization of superconducting cables elsewhere "within the next few years." Because the superconducting materials still must be cooled down to liquid-nitrogen temperatures, applications are likely to be limited to relatively short-range transmission in underground cables, rather than long-distance transmission. But that could still be a savior for a number of cities whose maxed-out underground transmission systems are literally burning up.

Then there is the matter of getting cheap electricity to Long Island, one of the country's fastest growing areas. There, too, power electronics could change everything. The problem is that New York City literally stands between Long Island and cheap power. Squeezing more electricity past this massive bottleneck is nearly impossible. The transmission lines running into New York City are simply too full to carry additional power onward to Long Island. So while Connecticut residents just 40 kilometers away across the Long Island Sound gorge on vast amounts of cheap juice flowing down from Canada's hydroelectric plants, the eccentricities of the existing grid mean electrically isolated Long Islanders must fend for themselves, relying on local generators to supply a hefty 93 percent of peak power demand. This is one reason that Long Island endures some of the highest electricity rates in the country.

Power electronics is providing a solution so compelling that it is driving the construction of the first U.S. high-power line built by transmission entrepreneurs, who see a huge profit in bridging Long Island's power gap. As in the Marcy system, two power processors will control energy flow on this transmission line, which will stretch underneath the sound. But instead of sitting back-to-back as they do at Marcy, the processors will lie on opposite shores, sucking AC power out of one grid, pumping it as DC power under the sound via a 42-kilometer underwater cable, and regenerating the AC wave on the other side. (The conversion to DC cuts costs, because underwater AC cables are more expensive than their DC counterparts.) "You want 100 megawatts to go in one direction? Just turn the dial. Want it in the other direction? You just turn the dial," says Jeffrey Donahue, president of TransÉnergie U.S., a subsidiary of Montreal-based power giant Hydro-Québec and the builder of the $120 million link.

ANARCHY RULES

New York's power problems rank among the country's toughest because the state's grid is particularly complex and congested, but its situation is far from unique. Grid operators up and down the eastern seaboard are straining to meet rapid growth in electricity demand, while persistent regional bottlenecks present a constant

The brawn: Each of the power valves (bottom right) at Marcy is composed of six thyristors and associated diodes and heat sinks.

cause of worries in the Midwest. (TransÉnergie is eyeing several projects, similar to the one in Long Island, to span the Great Lakes.)

Fortunately, even as the problems escalate, power electronics may be about to benefit from smaller and cheaper silicon switches—in the same way PCs have benefited from faster and cheaper computer chips. Call it Moore's Law for power electronics. Quicker switches providing cheaper power processors mean that, for the same buck, grid operators can install larger systems with greater impact on the grid. And that's good news for grid controllers, for whom power over power is intoxicating. "Now that I understand what it does, I wish it was bigger," says Len Panzica, one of the controls engineers who put Marcy's system through its paces this spring.

The grand vision, of course, is to electronically tame the nation's vast power network. Unlike isolated devices that regulate a few lines each, integrated network controls could synchronously tweak all of a system's electronics to optimize flow over the entire grid. Stahlkopf of the Electric Power Research Institute estimates that integrated control could boost the overall transmission capacity of existing infrastructure by 30 to 40 percent. Stahlkopf figures this leap forward is at least 10 years off, but he says utilities are already beginning to take an important step—wide-area telemetry providing operators with a real-time picture of how much power is flowing over their lines and from where.

However, with anarchy gripping today's power grid, integrated controls—even in a decade from now—seem like a bit of a pipe dream. Rapid deregulation has swept away the old rules without offering coherent alternatives for who should run the network and how they will get paid for it—making it an especially tough time to market advances offered by power electronics.

New systems like those at Marcy are even more politically charged because they can spontaneously reconfigure the grid, potentially increasing the strategic value of some power plants and idling others. LaRose says the Marcy project has few enemies because it can only shift a few hundred megawatts in a system that handles over 30,000 megawatts daily. But he says a larger project could find itself facing formid-able opposition. To implement these new technologies, you've "got to walk very gingerly through that minefield," says LaRose.

What's more, power electronics aren't cheap. Even with Siemens, the Electric Power Research Institute and 21 utilities keen to demonstrate the technology chipping in $13 million for the Marcy project, the New York Power Authority must come up with $35 million more, which it's attempting to do by selling bonds to wary financial investors. With the rules for transmission investments in flux, there is a real possibility that the Power Authority will never fully recoup its investment.

So why roll the dice on expensive equipment? The engineering answer is that for the foreseeable future, anyway, power electronics is the best hope for stabilizing the electric grid. The more pragmatic answer is that the New York Power Authority, a state-owned corporation, is directly accountable to politicians who fear the wrath of voters if the rolling blackouts darkening California's economy roll across the Empire State. Unfortunately, it may take a few more dark days and cold nights without electricity before the rest of the grid's numerous interested parties begin to see the light. TR

Uphill battle: National Cancer Institute director Richard Klausner sees DNA chips as potent weapons against cancer.

HAMADA

DNA Chips Target Cancer

Within a few years, DNA microarrays could help diagnose and treat this killer, perhaps even before tumors form. BY MARC WORTMAN

PHOTOGRAPHS BY KYOKO HAMADA AND TIMOTHY ARCHIBALD

In preparation for minor surgery, John Leventhal needed a routine chest x-ray. When the New Haven, CT, doctor joined the radiologist who was examining the film, he was shocked by what he saw: an opaque blotch deep in his lung. "As a physician," says Leventhal, "you're taught in medical school that when you see a mass like that, it means lung cancer." Leventhal's medical training also taught him that to confirm the diagnosis, his doctors would need to crack open his rib cage to get a piece of the suspect tissue that would be closely examined by a pathologist—an extremely painful and hazardous operation. The weekend before that surgery, Leventhal went off on a family ski vacation. He recalls thinking, "This is the last time I will go skiing for a long, long time."

That was five years ago. Today the medical profession's way of dealing with cancer could be about to change. Around the same time that Leventhal underwent surgery, researchers at Stanford University and Santa Clara, CA-based startup Affymetrix were beginning to build the first "DNA microarrays." More commonly known as DNA chips, these are DNA-covered silicon, glass or plastic wafers capable of analyzing thousands of genes at a time to, for example, identify the ones that are active in a sample of cells. Now these microarrays appear poised to join the war on cancer. DNA chips, predicts National Cancer Institute director Richard Klausner, are "going to have a huge effect" on the diagnosis and treatment of the disease.

One reason for the excitement is that DNA chips offer a whole new—and potentially much earlier, easier and more precise—way of detecting cancerous cells.

Most forms of cancers go unnoticed until lumps, coughs or pains develop, at which point it is often too late. And even then, once a pathologist gets a biopsy from a tumor, distinguishing one form of cancer from another can be difficult or even impossible with existing techniques, which involve noting distortions in the cells' architecture under a microscope. Better diagnostic information could be used to make better treatment decisions, perhaps making the difference between life and death.

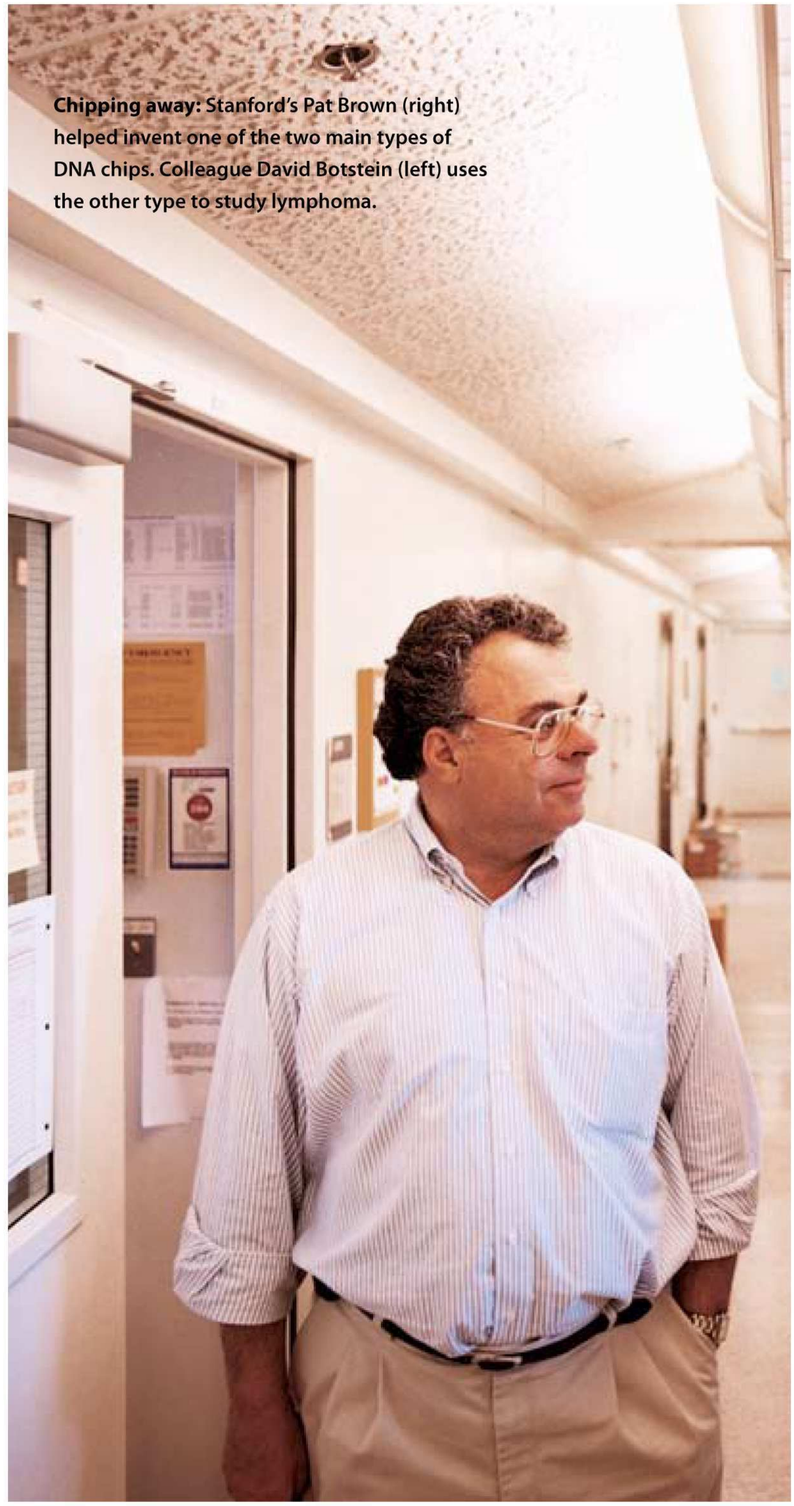
Within the next two years, pathologists expect to begin using DNA-chip-based tools to spot genetic differences among cells; these telltale differences could be used to help detect cancerous cells long before symptoms develop and to distinguish one type of cancer from another. In short, the chips will provide a genetic profile of a cancerous cell that can be read like a criminal's rap sheet. The physician will know where the cancerous cell originated, how far it has progressed, and which therapies will work best to halt its further growth and spread.

Leventhal was lucky. His lung biopsy was negative, and he was back on the slopes the next winter. But it took him a month to recover from the biopsy surgery, and today he has an angry scar down the middle of his chest to remind him of the ordeal. By the end of the decade, it is likely that a patient like Leventhal will be able to skip invasive diagnostic procedures altogether. A DNA-chip-based device might be able to read a sputum sample right in the doctor's office, checking for the genetic changes in the lung cells that are naturally sloughed off into the viscous fluid. If the news is bad, the patient might well have a host of new treatment options. That's because DNA chips are also speeding the discovery of new and better cancer drugs. "We're on the threshold of a new era," says Klausner. "Technologies like DNA chips will tell us not only that something may be amiss, but what it is and what we can do about it."

Gathering Speed

With one out of every two men and one out of every three women in the United States likely to get cancer at some point in their lives—and about 560,000 Americans expected to die of the disease this year alone, according to the American Cancer Society—advances can't come fast enough. As many as 500 research laboratories in academia and industry are already employing DNA chips to develop sweeping new genetic pictures of different cancers. In 1999, the National Cancer Institute alone provided \$4.1 million to 24 U.S. academic cancer institutions to set up or upgrade microarray centers. Meanwhile, the pharmaceutical and biotech industries are drawing on information gleaned from DNA chips to develop new and better diagnostic tests and more effective anticancer drugs with fewer side effects *(see "Corporate Cross Section," p. 55)*. Indeed, all the major drug companies and at least a dozen biotech firms are already using DNA chips to tackle cancer.

At the same time, large manufacturing companies such as Agilent Technologies, Corning and Motorola are seeing the potential of DNA chips. All three have allied with academic research centers to come up with DNA chips that will analyze genes related to specific cancers. And while at the moment DNA chips are far too expensive to compete with existing diagnostic technologies, the involvement of these manufacturers and their production facilities could drop prices as low as \$10 for a chip, once large-volume production gears up.



Chipping away: Stanford's Pat Brown (right) helped invent one of the two main types of DNA chips. Colleague David Botstein (left) uses the other type to study lymphoma.

ARCHIBALD

Of course, for DNA chips to help win the war on cancer, it will take considerable effort—and years of further development. For one thing, DNA chips generate tons of data, and researchers will need to beef up their computing capabilities and nail down data standards in order to make sense of it all *(see "Gene Babel," TR April 2001)*. And any new drugs or diagnostic devices will have to prove themselves in clinical trials. But the initial fruits of the efforts to apply DNA chips to cancer—new diagnostic tools—could begin saving lives as early as the end of next year. The first anticancer drugs developed using DNA chips will enter human trials around the same time, with dozens more to follow. With all those new tools available, currently untreatable forms of cancer may, one day, no longer mean death sentences.

Profiles in Cancer

The first step toward that grand vision is generating a profile of the genes that are activated or shut down when a normal cell becomes cancerous. While most genes are quiet in any given cell at any given time, the ones that are active, or "expressed," tell a lot about that cell's health. And though many of us tend to think of diseases as being caused by particular genes—say the gene for Huntington's disease or cystic fibrosis—most diseases actually involve complicated interactions among a large set of different genes. However, just as a person's fingerprints can be distinguished from virtually all others by just a small number of differences, a sort of genetic fingerprint, perhaps involving a hundred active genes or even fewer, could distinguish cells showing even the very earliest signs of cancer.

The beauty of using a technology like DNA chips to find those fingerprints, says Klausner, is that "we're not limited by preconceived knowledge or notions." In other words, cancer investigators no longer have to bias their experiments by looking individually at the genes they suspect might be involved with a particular cancer. "Instead of focusing on one gene," explains National Cancer Institute researcher Louis Staudt, "with microarrays we get to look at the entire genome and let the cancer cell tell us what the important genes are."

The flagship in the National Cancer Institute's efforts to demonstrate the validity of the DNA-chip approach is the so-called Lymphoma/Leukemia Molecular Profiling Project, which is directed by Staudt. The study is looking at diffuse large B-cell lymphoma, a relatively common cancer of the white blood cells that affects more than 15,000 people in the United States each year. When oncologists give those patients standard chemotherapy treatments, about 40 percent respond rapidly. Their cancer melts away, and the majority are still alive five years after diagnosis. But of that other 60 percent, most are not so lucky. The cancer may go into remission briefly, but when it returns, it comes back with a vengeance. A few patients benefit at that point from radiation treatments and bone marrow transplants, but for most it is already too late to halt the spread of the disease. Clearly there is something different about the two groups, but under a pathologist's microscope their cancer cells look identical.

The surprising answer is that these patients respond differently to treatment because, in fact, they are suffering from completely different types of lymphoma. Using what they dubbed a "Lymphochip," a customized Affymetrix DNA chip, Staudt and a group at Stanford led by geneticist David Botstein discovered distinctive genetic differences between the cancers in the patients with large B-cell lymphoma who died and those who survived. "I was blown away by what we found," says Botstein. Effectively, they were looking at two different illnesses. "It's remarkable," says Staudt. "We found something in this disease that was missed for all the years pathologists were looking at it."

Similar projects are now under way to profile various forms of cancer, from different types of melanoma to colon cancer. Most other cancers present pictures similar to that of lymphoma: some patients get better and some do not, but predicting who will respond to therapies is impossible. If there were some way to identify the patients who won't respond to standard chemotherapy, doctors could turn immediately to alternative treatments—and save lives. Indeed, says Pat Brown, a Stanford University School of Medicine geneticist who helped invent one of the two main types of DNA chips, "The same story is coming out for a bunch of cancers we look at—cancers with different clinical outcomes have different molecular subtypes." And knowing the precise subtype of cancer afflicting a patient could help doctors pick the right treatments, right from the start.

Perfecting Detection

Once researchers know the fingerprints of different cancers, they'll be able to craft customized DNA chips that doctors can use to diagnose patients with previously unheard-of accuracy. Says Staudt, "The textbooks on cancer diagnostics are going to be rewritten over the next three to four years.... [DNA-chip-based diagnostics] will very soon become routine technology."

But the ability to read subtle genetic changes could allow doctors to do more than pinpoint the exact identity of a cancer; it could also help them read early warning signs that normal cells are about to turn cancerous—long before such changes are evident to a pathologist. That's what University of South Florida cancer geneticist Melvyn Tockman is hoping, anyway. He and his colleagues are working on an early-detection method for lung cancer—a method that could make John Leventhal's scar a relic of the medical dark ages.

The researchers take sputum samples from ex-smokers and use DNA chips to analyze which genes are active in the lung cells. By comparing the genetic profile of these damaged cells to profiles from both healthy and cancerous lung cells, Tockman hopes to find the fingerprint that indicates a cancer is just about to form. In the future a patient at risk for lung cancer might take a simple DNA-chip-based test for this genetic fingerprint each time he went for his regular checkup.

That's a few years in the future, but the initial payoff of DNA chips in detecting cancer may come even sooner. Researchers are already using the chips to identify telltale proteins that can be detected by conventional cancer-screening tools. "If a cancer has one hundred uniquely expressed genes," explains Mohan Iyer, the vice president of business development at Santa Clara, CA-based diaDexus, "the home run hit is to find one [of the proteins those genes code for] that can be used in a simple blood test to screen individuals for cancer." If a protein were found to be unique to a certain cancer, says Iyer, standard hospital equipment could easily detect it in a blood sample.

Discount drugs: Rosetta Inpharmatics' Stephen Friend says DNA chips will help develop new treatments at a tenth of the usual cost.

ARCHIBALD

With DNA-chip tools now helping to identify the proteins associated with breast, lung, colon and ovarian cancer, to name a few, Incyte Genomics, Corning and a handful of other companies are developing new protein-based screening methods for diagnosis of the diseases. These new tests should begin to reach diagnostic laboratories in the next two years or so.

Remedies, Rapidly

But better diagnostics will begin to make a real difference only when they're coupled with more effective treatments, treatments that are fine-tuned to combat particular types of cancer. Even "if you can distinguish 50 different lymphomas," says Yale University School of Medicine pathologist Michael Kashgarian, "what does it matter whether it's type A or type Z if the therapy is the same?"

In this area of cancer drug discovery, DNA chips are also playing a key role. Just as the rapid analysis of a large number of genes is helping to profile cancer for better diagnostics, it is also providing valuable clues to how to attack cancer cells.

Researchers have long believed that developing new therapies would begin with finding cancer-associated genes, but the past two decades have been filled with disappointment. Stephen Friend, once an oncology researcher at the Whitehead Institute for Biomedical Research in Cambridge, MA, and now chief executive officer of Rosetta Inpharmatics in Seattle, blames what he calls the "my-favorite-gene approach." Biomedical researchers would spend years tracking down one gene associated with a particular cancer, then proceed on the assumption that that gene, or the protein it coded for, would make a great target for new drugs. But, Friend says, "the chances were in 999 out of 1,000 cases that you'd be wrong." Very few genes work alone and in such simple and direct relationships with the body to cause disease. "God, were we stupid!" he says.

Friend is now convinced that technologies such as DNA chips that allow researchers to find all the genes involved in a disease are the way to go. (Rosetta plays a role in such research by selling software and other services for reading microarrays.) Not only can DNA chips help identify all the potential drug targets for a given type of tumor, they can also help rule out the genes that are active in healthy tissues. That way, drugmakers can develop precisely targeted treatments that kill cancer cells without damaging other parts of the body. "Drugs," says Friend, "are going to be developed at a tenth the cost and in a third of the time by improving targeting and making sure compounds don't pick up unwanted side effects."

Eos Biotechnology, a South San Francisco company that is developing new cancer therapies using DNA chips from its partner Affymetrix, is betting he's right. In the company's labs, vice president of genomics research David Mack holds up one of those chips, which contains virtually the entire set of human genes. "The ability to generate the human genome on a chip today is incredible," he says. Eos uses the chips as a platform on which to compare genetic activity in normal human cells and, say, a breast-cancer cell. Computers can then sort out the genes that are active only in the diseased cell. Moreover, they can select just those genes that present the best targets for drugs.

Under the traditional drug-development paradigm, once researchers identify a set of potential targets, they begin to stumble ahead into animal and human trials, with educated guesses about which potential drugs might be effective against a given target, and which of those drug candidates might have toxic side effects. Very often, it's only much later in the process that a candidate's problems become apparent—at a huge cost in time and money.

By contrast, Eos continues to use microarrays and other high-volume genomic techniques to test the drugs, better predicting which will be the most effective and the least toxic before more costly testing even begins. According to Mack, "We're seeing data-driven science now, which hasn't been the previous paradigm." Thanks in part to the use of DNA chips, the company plans in the coming year to begin clinical testing of its first drug—which attacks a tumor's ability to generate its own life-sustaining blood supply—with more than a dozen other anti-cancer drugs expected to follow rapidly. "The promise of these technologies to impact patients is here—finally," he says.

While DNA chips have only been around for five years or so, they have already helped to get a number of new drugs into pharmaceutical-company pipelines, and to identify many potential new drug targets and sources of earlier diagnosis. With these advances, it is likely that cancer therapy will become both more complex and more effective over the next decade. Eventually, each patient's cancer fingerprint will be met with just the right drug "cocktail," or combination of therapies. Doctors will have new tools to diagnose and treat cancers much earlier—when the chances of cure are far better—and to monitor a patient's progress, ensuring that tumors don't develop resistance to the treatment.

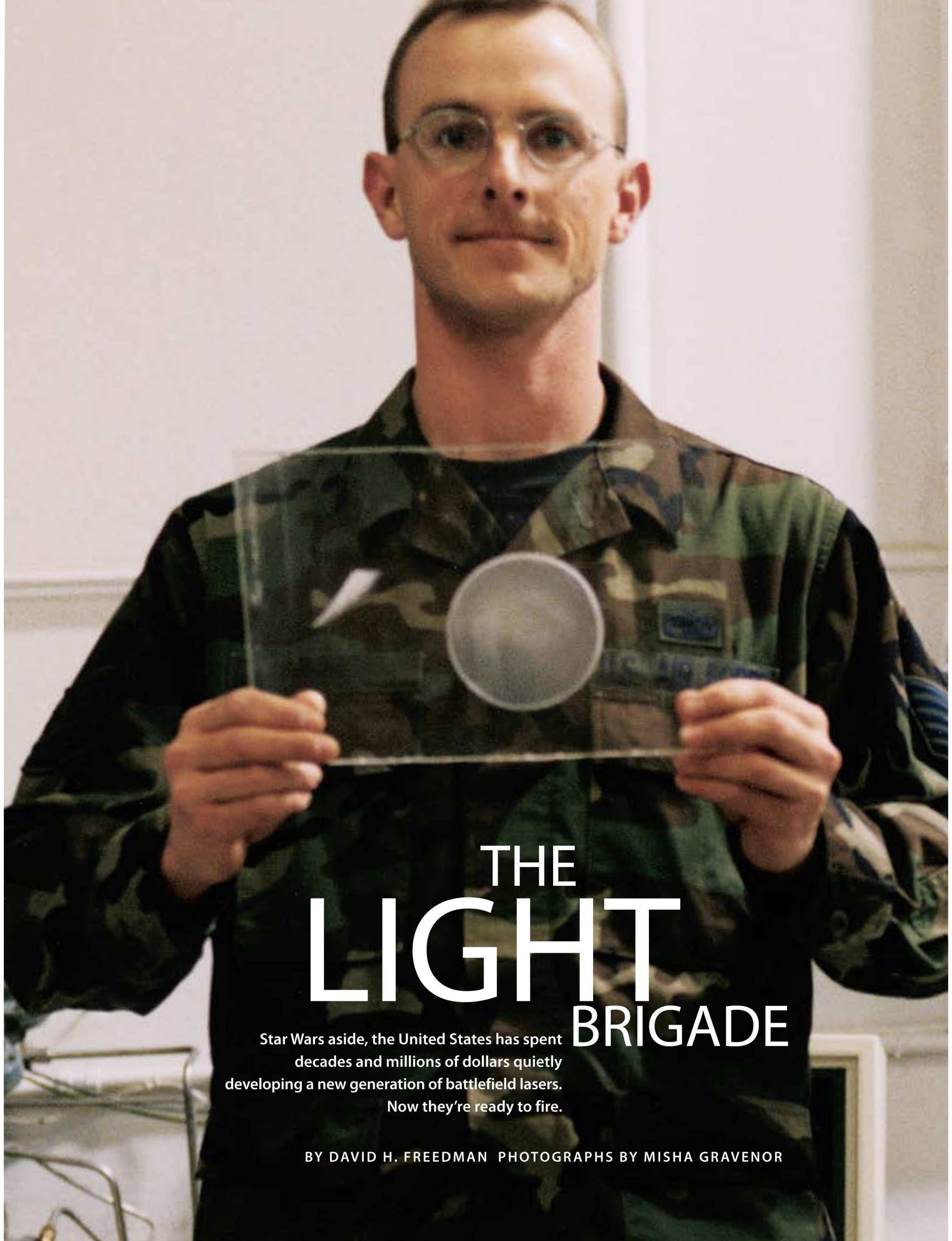
It may take more than a decade before such practices become the norm, but if and when they do, they will change everything for people like John Leventhal. His (mis)diagnosis of lung cancer came when he was the age at which his own father got news of the cancer that eventually killed him—a fact that ratcheted up Leventhal's terror when he learned he might have cancer. But should his children ever find themselves in the same shoes, perhaps they won't have nearly as much to fear. TR

Corporate Cross Section

Some of the firms putting DNA chips to work in the war on cancer

COMPANY	LOCATION	FOCUS
Affymetrix	Santa Clara, CA	DNA chip manufacturing
Agilent Technologies	Palo Alto, CA	DNA chip manufacturing
Corning	Corning, NY	DNA chip manufacturing
diaDexus	Santa Clara, CA	Diagnostics
Eos Biotechnology	South San Francisco, CA	Therapies
Incyte Genomics	Palo Alto, CA	Software and data tools
Medigene	Martinsried, Germany	Therapies
Millennium Pharmaceuticals	Cambridge, MA	Diagnostics
Molecular Engines Laboratories	Paris, France	Therapies
Motorola Clinical Micro Sensors	Pasadena, CA	Diagnostics
Rosetta Inpharmatics	Seattle, WA	Software and data tools

Firing photons: At Kirtland Air Force Base in New Mexico, a test laser probes the effects of high energy on various materials. **Opposite:** Technical Sergeant Steven Tuss holds a Plexiglas target used to calibrate the beam.



THE LIGHT BRIGADE

Star Wars aside, the United States has spent decades and millions of dollars quietly developing a new generation of battlefield lasers. Now they're ready to fire.

BY DAVID H. FREEDMAN PHOTOGRAPHS BY MISHA GRAVENOR

A HOWITZER IS A CRUDE-LOOKING WEAPON, ESSENTIALLY A SMALL SMOKESTACK WITH A DOOR AT THE BOTTOM THAT ALLOWS THE INSERTION OF BREAD-BOX-SIZED SHELLS. BUT OPERATING ONE REQUIRES a year of specialized schooling. That's because howitzers, like most artillery guns, are "indirect fire" weapons—that is, if you aim directly at your target, you'll literally miss by a mile, and probably by several. Adjustments have to be made for distance, wind, temperature, atmospheric density, humidity, the amount of wear in the barrel and the spin of the earth (aim left in the Northern Hemisphere, right under southern skies). Even then, most of the shell's explosive force will not end up precisely where intended. Then, 30 seconds of frenzy among a crew of six sees a new shell dragged into the gun, and you can try again. For all this bother, though, howitzers remain the weapon of choice for delivering destruction at a distance.

A military expert, given a clean sheet of paper and asked to sketch out the howitzer's ideal replacement, might end up with something like this: fires weightless and unlimited ammunition, is mountable on aircraft or ground vehicles, can be aimed directly at a target, reloads instantly, tracks fast-moving targets, shoots with pinpoint precision, creates no risk of collateral damage. In the end, he or she would have essentially described a class of weapon that could play a significant role in the next major U.S. armed conflict—weapons that hurl photons instead of chunks of metal.

The U.S. military is gearing up for laser warfare.

Of course, the idea of using high-powered lasers to destroy enemy missiles has been widely publicized ever since President Ronald Reagan pushed the "Star Wars" program—the Strategic Defense Initiative—in the early 1980s. But far less recognized—and less speculative—is the prospect that more down-to-earth laser weapons may soon revolutionize all types of combat, thanks to an intense, four-decade-long research and development effort that's poised to pay battlefield dividends. From versions that fill a 747 airplane to devices that fit in a Humvee, lasers are already destroying military targets in tests and are likely to be deployed over the next decade in everything from full-scale warfare to peacekeeping actions to terrorist encounters.

The U.S. military and its contractors have been exceedingly discreet about these programs. And for good reason. Laser weapons remain highly controversial. In the early 1990s, for example, protests from groups that deem battlefield lasers inhumane because of their potential for blinding both civilians and combatants forced the military to shelve a secret laser system that would literally have given eyeball-blasting capabilities to foot soldiers. Though the newer programs appear to skirt international prohibitions on blinding weapons, protests are likely to be revived as the weapons come online. Stephen Goose, program director of the arms division of Human Rights Watch, concedes that the quiet fashion in which battlefield laser systems are being developed has temporarily taken them off of human- rights groups' radar screens. But that may be about to change. "No one is reviewing how these systems are being implemented," he says. "But questions need to be raised."

Despite such concerns, however, the military is going full speed ahead—and some experts feel laser weapons will soon give American troops a battlefield edge. "The introduction of optical and other directed-energy weapons, including advanced nonlethal weapons, will be as significant as the introduction of firearms and artillery was to the modern world," says Robert Bunker, an adjunct professor in the National Security Studies program at California State University, San Bernardino, and a professor at American Military University. Indeed, China and Russia also have reportedly been developing laser weapons for at least a decade, though in less powerful and accurate form.

FROM 'NAM TO BUCK ROGERS

The notion of laser-beam warfare may conjure images of a distant, Buck-Rogersian future. But military lasers date back to the Vietnam War, when they were first used to guide bombs to their targets. Targeting lasers don't pack any punch, but even then the Pentagon was funding research into high-energy lasers that would destroy rather than "designate" targets. Army and Navy lasers began shooting down small missiles and unmanned aircraft in limited late-1970s tests—and the programs accelerated in the next decade under Star Wars. But it wasn't until the mid-1990s that laser tracking and control systems became accurate enough for reliable weapons. Between Reagan's program and more recent funding, the government has put $14 billion into high-energy laser research and development. It's now spending some $200 million a year on general research—plus $400 million more on specific weapons programs. Those numbers are expected to nearly double under President George W. Bush.

The effort to bring lasers to the battlefield flashes to life at Kirtland Air Force Base in Albuquerque, NM, where a carbon-dioxide laser turned on only for a moment leaves a flaming eight-millimeter hole in a nearby slab of Plexiglas. This test unit carries a fraction of the power of any battlefield system. But what it reveals about the effects of lasers on various materials might soon find real-world application in one of three full-scale projects geared to take out short-range missiles, aircraft, tanks and even, if indirectly, individual soldiers and terrorists.

Warm-up act: Within moments of being turned on, the air force test laser sets a Plexiglas sheath aflame. **Opposite:** T.Sgt. Steven Tuss in the control booth.

Lock 'n' Load: A fire-control radar (bottom) detects incoming Katyusha rockets and relays trajectory data to the Tactical High-Energy Laser beam director (top).

The most visible project—one that stands to receive up to $2.7 billion in new funding under the Bush administration—is called the Airborne Laser, and it stuffs an oxygen-iodine laser into a modified Boeing 747. Like all lasers, it pumps chemical or electrical energy into a substance whose atoms reemit the energy as coherent light—a single, powerful beam that resists spreading.

In the military's scenario, 747s carrying these jumbo lasers will patrol 12,000 meters over ground held by friendly troops and other areas vulnerable to short-range ballistic missiles. These lasers can slap a beam packing as much as two megawatts of energy, enough to power a few small towns, on a target as far away as Boston is from New York—some 300 kilometers. Even a beam that powerful won't instantly burn through the metal on a missile. But it's still enough to shoot one down, since the pressurized fuel compartments on ballistic missiles rupture and then explode when their walls are weakened by intense heat.

Once a newly launched missile is located by conventional sensors such as radar, the hard part for the Airborne Laser is placing the basketball-sized beam on the streaking missile's fuel compartment—then holding it there for the five or ten seconds it takes to work its magic, all while atmospheric turbulence distorts the beam. The weapon therefore enlists computerized systems that monitor the target image, calculate the distortion and then adjust the beam to cancel it out.

The advantage is that each missile-killing shot will burn about $10,000 worth of chemical fuel (aircraft should carry enough fuel for about 30 shots), compared to the $1 million cost of a conventional antiballistic missile. "We'll be worldwide deployable as early as 2008," says air force colonel Lynn Wills, who heads Airborne Laser acquisition. Wills expects to field seven aircraft, two of which will be in the air over hot spots at any given time. Early prototypes of the laser and targeting systems are already undergoing testing at TRW's secluded facility north of San Diego. A prototype of an integrated 747 aircraft and laser is scheduled for a maiden flight and test firing in 2004.

Beams from the sky won't be the only lasers stabbing at enemy missiles, however. A second weapon, based on a deuterium-fluoride-powered laser and known as the Tactical High-Energy Laser, is aimed chiefly at the small, cheap rockets often used by guerrilla soldiers. The program kicked into high gear in 1996, shortly after Israel was hit by a wave of Russian-made Katyusha rockets launched by Hezbollah troops in Lebanon. Since then the U.S. has sunk about $170 million into the program, matched by about $80 million from Israel—although development is solely under American control. These lasers combine radar tracking with a targeting and control system somewhat similar to the Airborne Laser's. The system is mounted on the ground, though, and should be able to down a Katyusha for about $2,000. "The Katyusha costs about $1,000 on the black market," says Tom Romesser, who heads TRW's space and technology division. "You can stop one with a Patriot missile, but you can't keep putting a $1 million weapon against a $1,000 threat."

Resembling a spotlight on a turret, the weapon boasts a 10-kilometer range and since mid-2000 has shot down more than 20 rockets at the White Sands Missile Range in New Mexico. It can also handle aircraft. "It's very fast," says Dick Bradshaw, program manager for directed-energy technology at the U.S. Army Space and Missile Defense Command in Huntsville, AL. "Nothing can maneuver out of the way once it's locked on. How are you going to get away from a photon?" The system is mounted on a concrete platform and stands the size of a small garage. But Bradshaw expects to see it shrunk to one-fifth that size; it could then be mounted on a truck for relatively fast transfers.

Having brought laser weapons down to the battlefield for fighting rockets and planes, it was only natural that the military would literally lower its sights and go after ground-based targets like tanks, trucks and artillery. The bet on this front is called the Advanced Tactical Laser. Also run by the Army Space and Missile Defense Command—with Boeing as prime contractor—the program aims to put a scaled-down, 300-kilowatt version of the oxygen-iodine weapon on a helicopter or small plane to be used against targets as far away as 20 kilometers. Managers expect to eventually build a truck- or Humvee-mounted system as well.

Katyusha catcher: A Tactical High-Energy Laser prototype intercepts and destroys a Katyusha at the army's White Sands Missile Range in New Mexico.

PHOTOGRAPHS COURTESY OF TRW

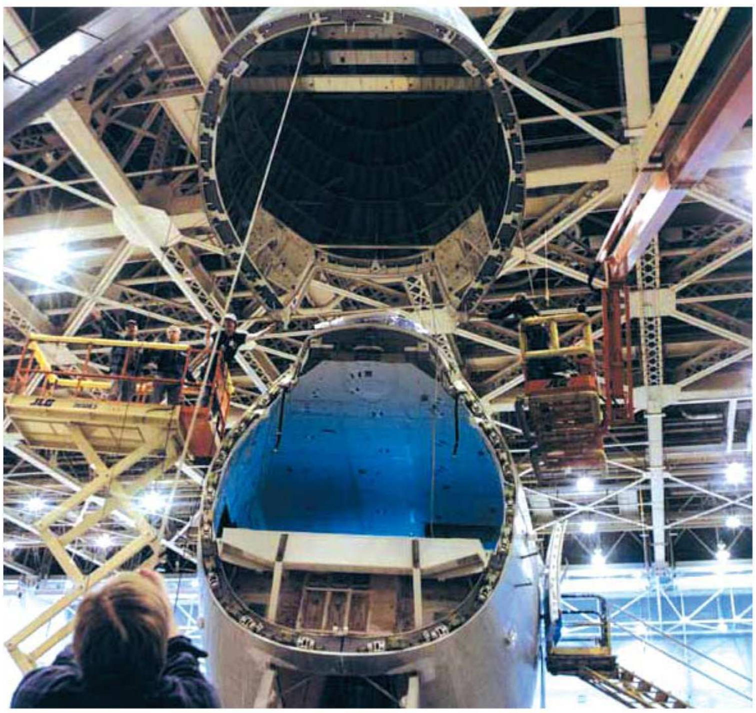
KILLING TANKS

Many observers argue that laser weapons should stick to fighting missiles, rockets and aircraft because these targets tend to destruct or crash when even a small part is damaged. Trucks and tanks are another matter altogether, says John Pike, director of Alexandria, VA-based defense-policy think tank Globalsecurity.org. "That's why bullets and shells are still popular—there's no way a laser is going to deposit more energy on a target than would have been created by an equivalent amount of chemical explosive."

In that view, killing a tank would be a stretch, given its 15-centimeter-thick armor plating. But the new idea is to disable, not destroy—and tanks have a high-tech Achilles' heel: their dependence on electronic communications and sensors to know what's going on. Melting a tank's antennas would be easy for a 300-kilowatt laser. Explains Colonel Mark Stephen, who helps manage the air force's laser weapons programs, "You can destroy or at least degrade a target without blowing it to bits." What's more, the loss of communications or other electronics systems would likely confuse the tank crew—and that could be all it takes to destroy the tank with conventional weapons.

With the ability to place a 10-centimeter-wide beam with the heating power of a blowtorch on distant targets for up to 100 shots, the Advanced Tactical Laser could wreak havoc on far more than tanks. One analysis noted that from seven kilometers away the system could also melt 11 antennas, blow out 32 truck tires and disable a mix of a dozen mortars, rocket launchers and machine guns before having to refuel. For all its potential, however, this weapon faces some unique headaches. Ground vehicles bounce and vibrate more heavily than aircraft, for starters, and if the laser is ever deployed on such vehicles it will require computer-controlled shock absorbers. In addition, intense ground battles tend to produce laser-blocking smoke and dust. And getting chemical fuel to a remote, hotly contested battleground could be difficult.

A research effort earmarked for $100 million in funding starting in 2003 is looking to solve the fueling problem. The goal is to replace the current chemically fueled laser with a solid-state weapon that gets its energy from an electric current directed into an



yttrium-aluminum-garnet compound, doped with neodymium. Laboratory versions of solid-state lasers currently put out a meager 10 kilowatts of power. But Bradshaw believes that figure will be upped to 100 kilowatts—enough to serve as a weapon.

Even farther down the road, researchers hope to replace the yttrium-aluminum-garnet compound with super-energy-efficient fiber-optic lasers like those already used in some telecommunications applications. A fiber-optic laser might fit in a Humvee and, because it would be electrically powered, could run off of the vehicle's generators, shedding the burden of resupplying special fuel. "You'd have to haul around some additional diesel fuel, but that's not much of a price to pay for being able to electrically generate your bullets right there in the field," says Bradshaw.

HUMAN-RIGHTS CONCERNS

While there is no guarantee these systems will develop on the smooth trajectory envisioned, the military sees several promising ways around the technological challenges, which is why it can now talk concretely about deployment. Perhaps the biggest obstacle faced by battlefield lasers isn't technological, however. For some 20 years, human-rights groups have opposed these weapons on the grounds that they are likely to blind people.

In the face of international pressure, the United States has already backed away from some of its laser ambitions. William Horton, a former army lieutenant colonel who worked on battlefield lasers for years until the early 1990s, confirms that the U.S. military long worked to develop vehicle- and backpack-mounted lasers designed to locate and blast enemy optical lenses such as periscopes or binoculars—with likely disastrous results for any enemy eyes peering through them. When reports circulated in the press about these efforts around 1985, protests ensued, and the systems didn't reach production (Horton says two vehicle-mounted prototypes were deployed in the Gulf War, but not used). Then, in 1995, the United States signed an amendment to the Geneva Convention protocols that prohibits blinding weapons.

The military always had a way out, since weapons designed to kill people or destroy objects—and that only carry a risk of blinding—are exempted from the ban. That's a loophole big enough to fly a laser-equipped 747 through, which is why deploying battlefield lasers remains viable. But even if the armed services are legally off the hook, top brass realize that in developing such lasers they are flirting with a public-relations disaster. The idea of a blinded soldier—or worse, a nurse or child—paraded on the news as a victim of an invisible American beam could make this country's high-tech military seem like high-tech monsters.

As a result, the military remains queasy about calling attention to its interest in battlefield lasers. The programs aren't secret; that tactic already backfired once for the government with the optics-hunting laser projects. But the policy appears to be one of not volunteering information unless pressed—and even when pressed, most military and civilian managers involved in laser defense programs deny knowledge of initiatives intended to bring lasers to bear against ground targets. On one point, they're clear, however: human targets are strictly off limits. "We've done nothing in the area of antipersonnel applications," says Bradshaw. "Certainly not to blind someone, and we've gone even further, to do whatever it takes to not injure a human."

But this one isn't likely to stay on the back burner. Dominique Loye, who studies possible Geneva protocol weapons violations for the International Committee of the Red Cross in Geneva, argues that the mere fact a battlefield laser isn't intended to blind or harm people doesn't guarantee it will pass muster with international agreements against weapons that injure in cruel ways. After all, he notes, who knows what soldiers will do with them in the heat of battle? "When you have a powerful weapon in your hand, you might start off firing at the intended target," he says. "But if you're threatened by enemy soldiers, you might turn it against them and use it quite indiscriminately."

Such objections will only get more intense as laser-weapon programs progress. But given the promise of putting pinpoint, ammunitionless firepower into the hands of front-line soldiers, the military is likely to press on in its quest for a Star Wars battlefield. And just as likely, warfare will never be the same again. TR

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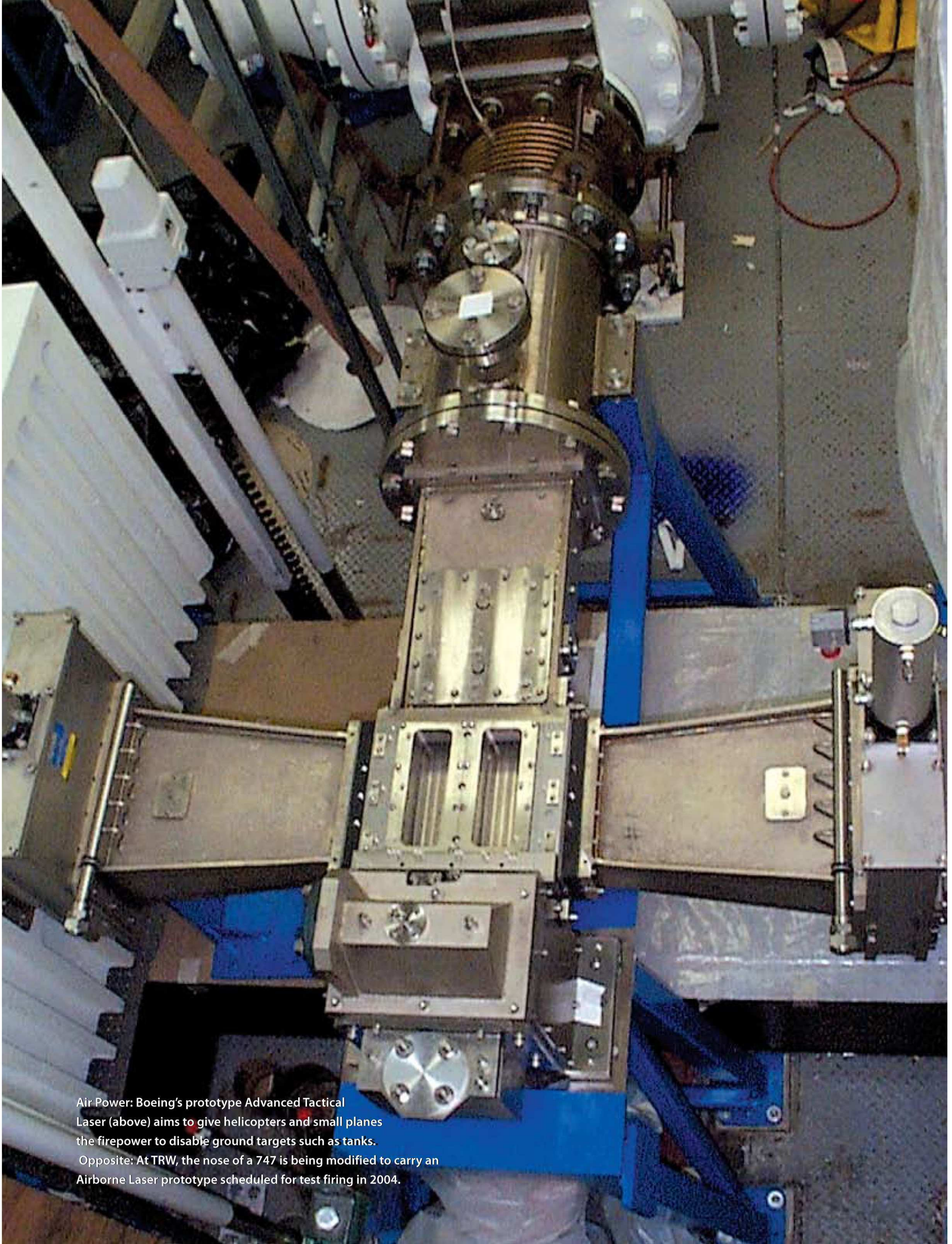
TEAM ABL (NOSE CONE); BOEING (LASER)

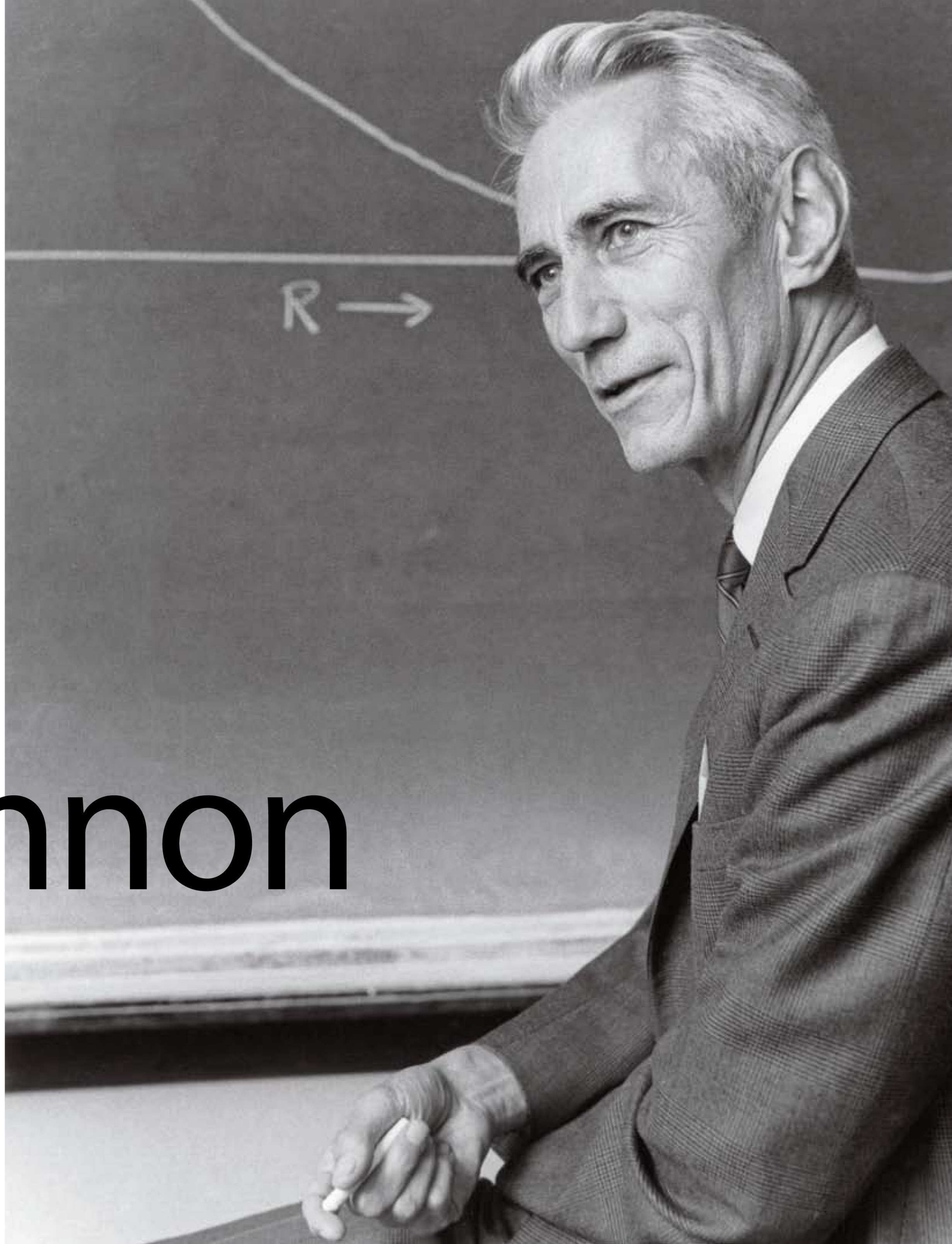


Air Power: Boeing's prototype Advanced Tactical Laser (above) aims to give helicopters and small planes the firepower to disable ground targets such as tanks. Opposite: At TRW, the nose of a 747 is being modified to carry an Airborne Laser prototype scheduled for test firing in 2004.

BY M. MITCHELL WALDROP

Reluctant Father of the Digital Age

Claude Shannon



COURTESY OF THE MIT MUSEUM

Pick up a favorite CD. Now drop it on the floor. Smear it with your fingerprints. Then slide it into the slot on the player—and listen as the music comes out just as crystal clear as the day you first opened the plastic case. Before moving on with the rest of your day, give a moment of thought to the man whose revolutionary ideas made this miracle possible: Claude Elwood Shannon.

Shannon, who died in February after a long illness, was one of the greatest of the giants who created the information age. John von Neumann, Alan Turing and many other visionaries gave us computers that could *process* information. But it was Claude Shannon who gave us the modern *concept* of information—an intellectual leap that earns him a place on whatever high-tech equivalent of Mount Rushmore is one day established.

The entire science of information theory grew out of one electrifying paper that Shannon published in 1948, when he was a 32-year-old researcher at Bell Laboratories. Shannon showed how the once-vague notion of information could be defined and quantified with absolute precision. He demonstrated the essential unity of all information media, pointing out that text, telephone signals, radio waves, pictures, film and every other mode of communication could be encoded in the universal language of

binary digits, or bits—a term that his article was the first to use in print. Shannon laid forth the idea that once information became digital, it could be transmitted without error. This was a breathtaking conceptual leap that led directly to such familiar and robust objects as CDs. Shannon had written "a blueprint for the digital age," says MIT information theorist Robert Gallager, who is still awed by the 1948 paper.

And that's not even counting the master's dissertation Shannon had written 10 years earlier—the one where he articulated the principles behind all modern computers. "Claude did so much in enabling modern technology that it's hard to know where to start and end," says Gallager, who worked with Shannon in the 1960s. "He had this amazing clarity of vision. Einstein had it, too—this ability to take on a complicated problem and find the right way to look at it, so that things become very simple."

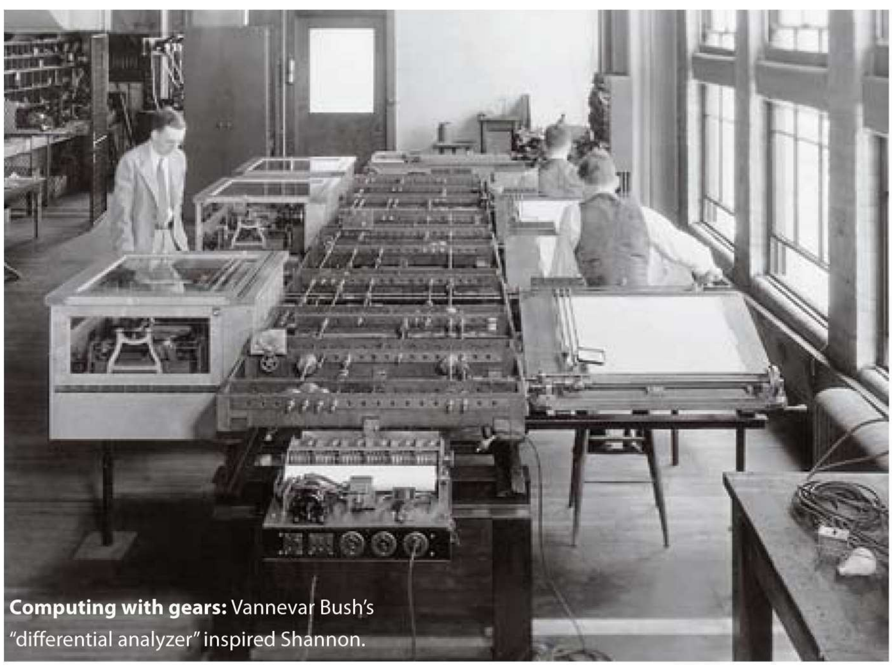
Shannon asserted that information could **be transmitted digitally** without error—a breathtaking conceptual leap.

Tinkering toward Tomorrow

For Shannon, it was all just another way to have fun. "Claude loved to laugh, and to dream up things that were offbeat," says retired Bell Labs mathematician David Slepian, who was a collaborator of Shannon's in the 1950s. Shannon went at math like a stage magician practicing his sleight of hand: "He would circle around and attack the problem from a direction you never would have thought of," says Slepian—only to astonish you with an answer that had been right in front of your face all the time. But then, Shannon also had a large repertoire of real card tricks. He taught himself to ride a unicycle and became famous for riding it down the Bell Labs hallways at night—while juggling. ("He had been a gymnast in college, so he was better at it than you might have thought," says his wife Betty, who gave him the cycle as a Christmas present in 1949.)

At home, Shannon spent his spare time building all manner of bizarre machines. There was the Throbac (THrifty ROman-numerical BAckward-looking Computer), a calculator that did arithmetic with Roman numerals. There was Theseus, a life-sized mechanical mouse that could find its way through a maze. And perhaps most famously, there was the "Ultimate Machine"— a box with a large switch on the side. Turn the switch on, and the lid would slowly rise, revealing a mechanical hand that would reach down, turn the switch off, and withdraw—leaving the box just as it was.

"I was always interested in building things with funny motions," Shannon explained in a 1987 interview with *Omni* magazine (one of the few times he spoke about his life publicly). In his northern Michigan hometown of Gaylord, he recalled, he spent his early years putting together model planes, radio circuits, a radio-controlled model boat and even a telegraph system. And when he entered the University of Michigan in 1932, he had no hesitation about majoring in electrical engineering.


Computing with gears: Vannevar Bush's "differential analyzer" inspired Shannon.

COURTESY OF THE MIT MUSEUM

After graduating in 1936, Shannon went directly to MIT to take up a work-study position he had seen advertised on a postcard tacked to a campus bulletin board. He was to spend half his time pursuing a master's degree in electrical engineering and the other half working as a laboratory assistant for computer pioneer Vannevar Bush, MIT's vice president and dean of engineering. Bush gave Shannon responsibility for the Differential Analyzer, an elaborate system of gears, pulleys and rods that took up most of a large room—and that was arguably the mightiest computing machine on the planet at the time *(see "Computing Before Silicon,"* TR *May/June 2000)*.

Conceived by Bush and his students in the late 1920s, and completed in 1931, the Differential Analyzer was an analog computer. It didn't represent mathematical variables with ones and zeroes, as digital computers do, but by a continuous range of values: the physical rotation of the rods. Shannon's job was to help visiting scientists "program" their problems on the analyzer by rearranging the mechanical linkages between the rods so that their motions would correspond to the appropriate mathematical equations.

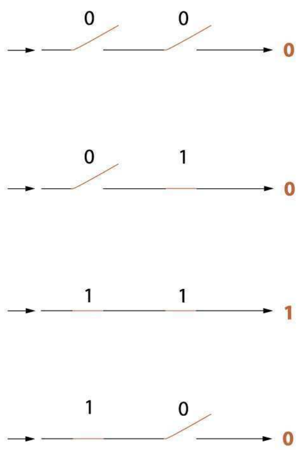
Shannon couldn't have asked for a job more suited to his love of funny motions. He was especially drawn to the analyzer's wonderfully complicated control circuit, which consisted of about a hundred "relays"—switches that could be automatically opened and closed by an electromagnet. But what particularly intrigued him was how closely the relays' operation resembled the workings of symbolic

The Logic of Circuits

Shannon saw the analogy between simple electronic switches and the logic operations that are at the heart of digital computing.

AND

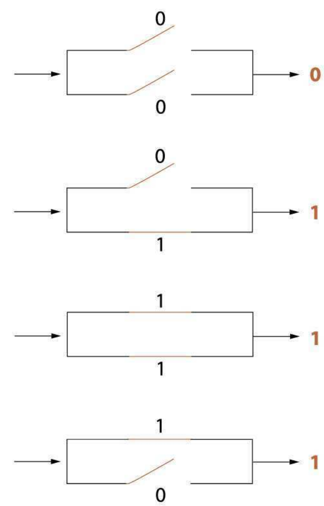
Shannon realized that networks of switches in circuits can carry out the operations of symbolic logic. If you line up two switches in a row, for example, they will embody the logical relationship AND. This means that the statement "current can flow through the circuit" is true only if both switches are closed.



OR

A circuit with two switches in parallel performs an OR operation, meaning that the current will flow if either switch is closed.

Shannon showed that any logical statement, no matter how complex, could be physically implemented as a network of simple switches.



logic, a subject he had just studied during his senior year at Michigan. Each switch was either closed or open—a choice that corresponded exactly to the binary choice in logic, where a statement was either true or false. Moreover, Shannon quickly realized that switches combined in circuits could carry out standard operations of symbolic logic *(see "The Logic of Circuits," above)*. The analogy apparently had never been recognized before. So Shannon made it the subject of his master's thesis, and spent most of 1937 working out the implications. He later told an interviewer that he "had more fun doing that than anything else in my life."

True or False?

Certainly his dissertation, "A Symbolic Analysis of Relay and Switching Circuits," makes for a compelling read—especially given what's happened in the 60-plus years since it was written. As an aside toward the end, for example, Shannon pointed out that the logical values true and false could equally well be denoted by the numerical digits *1* and *0*. This reali-zation meant that the relays could perform the then arcane operations of binary arithmetic. Thus, Shannon wrote, "it is possible to perform complex mathematical operations by means of relay circuits." As an illustration, Shannon showed the design of a circuit that could add binary numbers.

Even more importantly, Shannon realized that such a circuit could also make comparisons. He saw the possibility of a device that could take alternative courses of action according to circumstances—as in, "if the number X equals the number Y, then do operation A." Shannon gave a simple illustration of this possibility in his thesis by showing how relay switches could be arranged to produce a lock that opened if and only if a series of buttons was pressed in the proper order.

The implications were profound: a switching circuit could *decide*—an ability that had once seemed unique to living beings. In the years to come, the prospect of decision-making machines would inspire the whole field of artificial intelligence, the attempt to model human thought via computer. And perhaps by no coincidence, that field would fascinate Claude Shannon for the rest of his life.

From a more immediate standpoint, though, a switching circuit's ability to decide was what would make the digital computers that emerged after World War II something fundamentally new. It wasn't their mathematical abilities per se that contemporaries found so startling (although the machines were certainly very fast); even in the 1940s, the world was full of electromechanical desktop calculators that could do simple additions and subtractions. The astonishing part was the new computers' ability to operate under the control of an internal program, deciding among various alternatives and executing complex sequences of commands on their own.

All of which is why "A Symbolic Analysis of Relay and Switching Circuits," published in 1938, has been called the most important master's thesis of the 20th century. In his early 20s, Claude Shannon had had the insight crucial for organizing the internal operations of a modern computer—almost a decade before such computers even existed. In the intervening years, switching technology has progressed from electromechanical relays to microscopic transistors etched on silicon. But to this day, microchip designers still talk and think in terms of their chips' internal "logic"—a concept borne largely of Shannon's work.

Perfect Information

With the encouragement of Vannevar Bush, Shannon decided to follow up his master's degree with a doctorate in mathematics—a task that he completed in a mere year and a half. Not long after receiving this degree in the spring of 1940, he joined Bell Labs. Since U.S. entry into World War II was clearly just a matter of time, Shannon immediately went to work on military projects such as anti-aircraft fire control and cryptography (code making and breaking).

Nonetheless, Shannon always found time to work on the fundamental theory of communications, a topic that had piqued his interest several years earlier. "Off and on," Shannon had written to Bush in February 1939, in a letter now preserved in the Library of Congress archives, "I have been working on an

analysis of some of the fundamental properties of general systems for the transmission of intelligence, including telephony, radio, television, telegraphy, etc." To make progress toward that goal, he needed a way to specify what was being transmitted during the act of communication.

Building on the work of Bell Labs engineer Ralph Hartley, Shannon formulated a rigorous mathematical expression for the concept of information. At least in the simplest cases, Shannon said, the information content of a message was the number of binary ones and zeroes required to encode it. If you knew in advance that a message would convey a simple choice—yes or no, true or false—then one binary digit would suffice: a single one or a single zero told you all you needed to know. The message would thus be defined to have one unit of information. A more complicated message, on the other hand, would require more digits to encode, and would contain that much more information; think of the thousands or millions of ones and zeroes that make up a word-processing file.

As Shannon realized, this definition did have its perverse aspects. A message might carry only one binary unit of information—"Yes"—but a world of meaning—as in, "Yes, I will marry you." But the engineers' job was to get the data from here to there with a minimum of distortion, regardless of its content. And for that purpose, the digital definition of information was ideal, because it allowed for a precise mathematical analysis. What are the limits to a communication channel's capacity? How much of that capacity can you use in practice? What are the most efficient ways to encode information for transmission in the inevitable presence of noise?

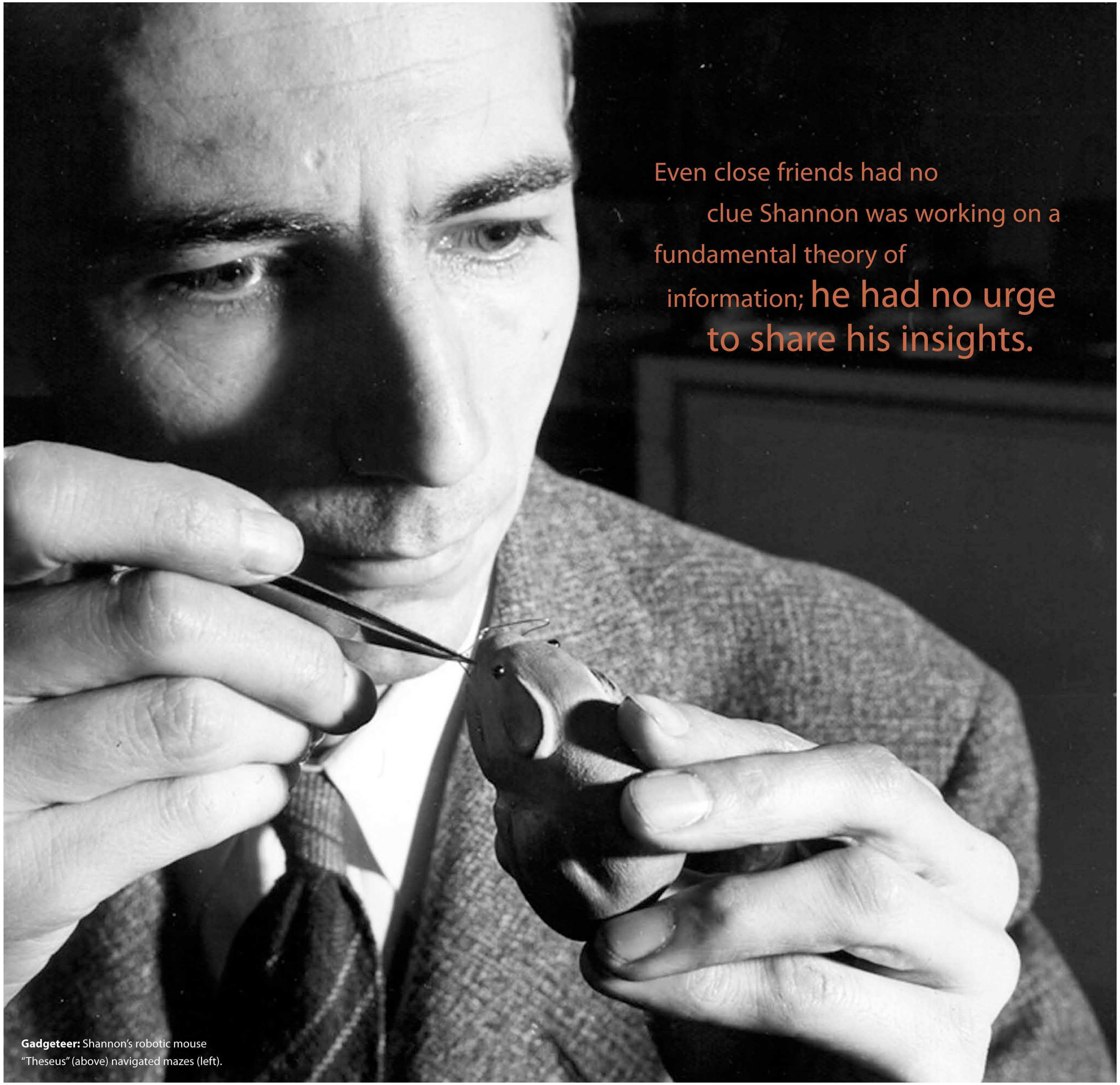
PHOTOS COURTESY OF AT&T LABS

Judging by his comments many years later, Shannon had outlined his answers to such questions by 1943. Oddly, however, he seems to have felt no urgency about sharing those insights; some of his closest associates at the time swear they had no clue that he was working on information theory. Nor was he in any hurry to publish and thus secure credit for the work. "I was more motivated by curiosity," he explained in his 1987 interview, adding that the process of writing for publication was "painful." Ultimately, however, Shannon overcame his reluctance. The result: the groundbreaking paper "A Mathematical Theory of Communication," which appeared in the July and October 1948 issues of the *Bell System Technical Journal*.

Shannon's ideas exploded with the force of a bomb. "It was like a bolt out of the blue," recalls John Pierce, who was one of Shannon's best friends at Bell Labs, and yet as surprised by Shannon's paper as anyone. "I don't know of any other theory that came in a complete form like that, with very few antecedents or history." Indeed, there was something about this notion of quantifying information that fired peoples' imaginations. "It was a revelation," says Oliver Selfridge, who was then a graduate student at MIT. "Around MIT the reaction was, 'Brilliant! Why didn't I think of that?'"

Much of the power of Shannon's idea lay in its unification of what had been a diverse bunch of technologies. "Until then, communication wasn't a unified science," says MIT's Gallager. "There was one medium for voice transmission, another medium for radio, still others for data. Claude showed that all communication was fundamentally the same—and furthermore, that you could take any source and represent it by digital data."

That insight alone would have made Shannon's paper one of the great analytical achievements of the 20th century. But there was more. Suppose you were trying to send, say, a birthday greeting down a telegraph line, or through a wireless link, or even in the U.S. mail. Shannon was able to show that any such communication channel had a speed limit, measured in binary digits per second. The bad news was that above that speed limit, perfect fidelity was impossible: no matter how cleverly you encoded your mes-



Even close friends had no clue Shannon was working on a fundamental theory of information; **he had no urge to share his insights.**

Gadgeteer: Shannon's robotic mouse "Theseus" (above) navigated mazes (left).

sage and compressed it, you simply could not make it go faster without throwing some information away.

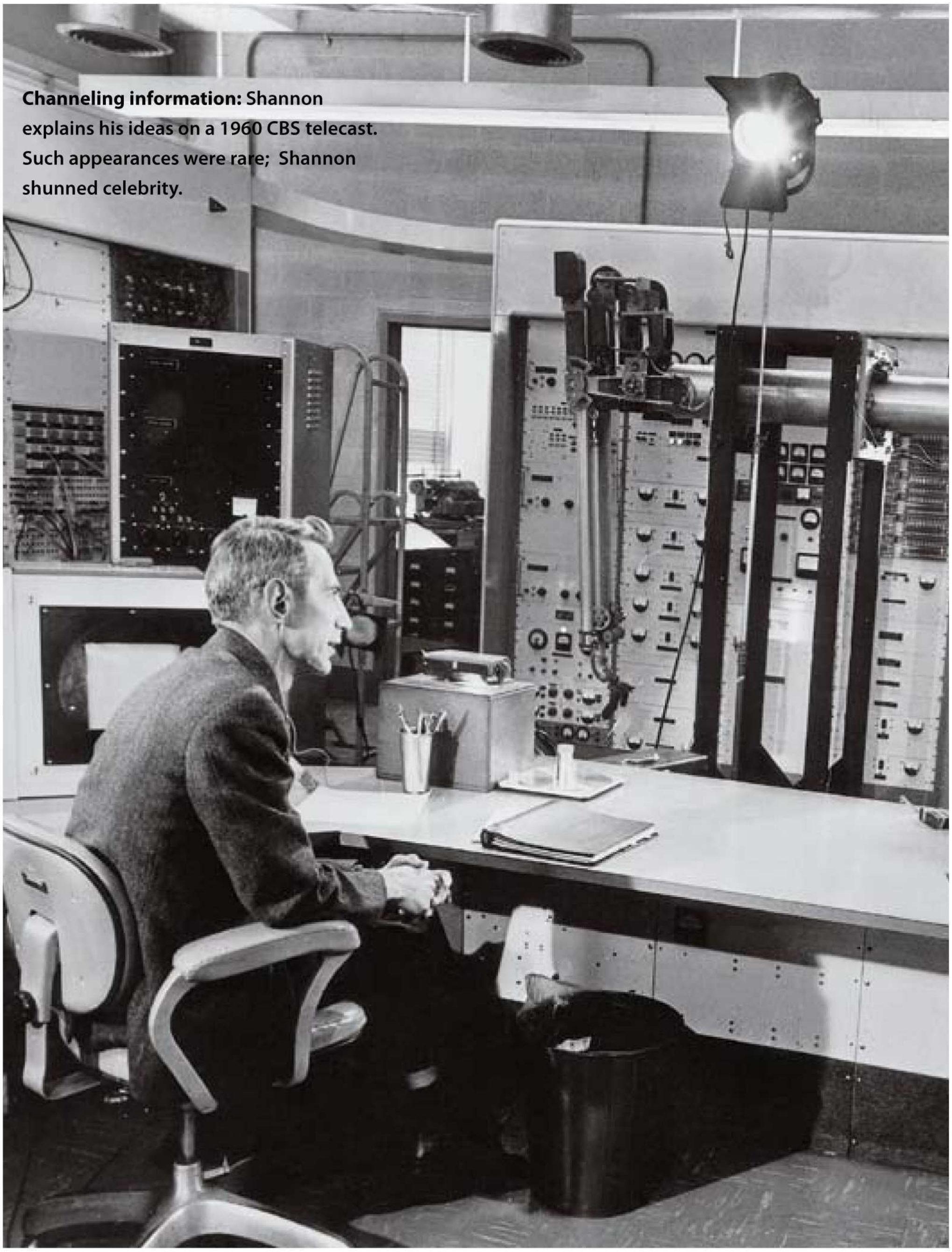
The mind-blowing good news, however, was that below this speed limit, the transmission was potentially perfect. Not just very good: perfect. Shannon gave a mathematical proof that there had to exist codes that would get you right up to the limit without losing any information at all. Moreover, he demonstrated, perfect transmission would be possible no matter how much static and distortion there might be in the communication channel, and no matter how faint the signal might be. Of course, you might need to encode each letter or pixel with a huge number of bits to guarantee that enough of them would get through. And you might have to devise all kinds of fancy error-correcting schemes so that corrupted parts of the message could be reconstructed at the other end. And yes, in practice the codes would eventually get so long and the communication so slow that you would have to give up and let the noise win. But in principle, you could make the probability of error as close to zero as you wanted.

This "fundamental theorem" of information theory, as Shannon called it, had surprised even him when he discovered it. The conquest of noise seemed to violate all common sense. But for his contemporaries in 1948, seeing the theorem for the first time, the effect was electrifying. "To make the chance of error as small as you wish? Nobody had ever thought of that," marvels MIT's Robert Fano, who became a leading information theorist himself in the 1950s—and who still has a reverential photograph of Shannon hanging in his office. "How he got that insight, how he even came to believe such a thing, I don't know. But almost all modern communication engineering is based on that work."

Shannon's work "hangs over everything we do," agrees Robert Lucky, corporate vice president of applied research at Telcordia, the Bell Labs spinoff previously known as Bellcore. Indeed, he notes, Shannon's fundamental theorem has served as an ideal and a challenge for succeeding generations. "For 50 years, people have worked to get to the channel capacity he said was possible. Only recently have we gotten close. His influence was profound."

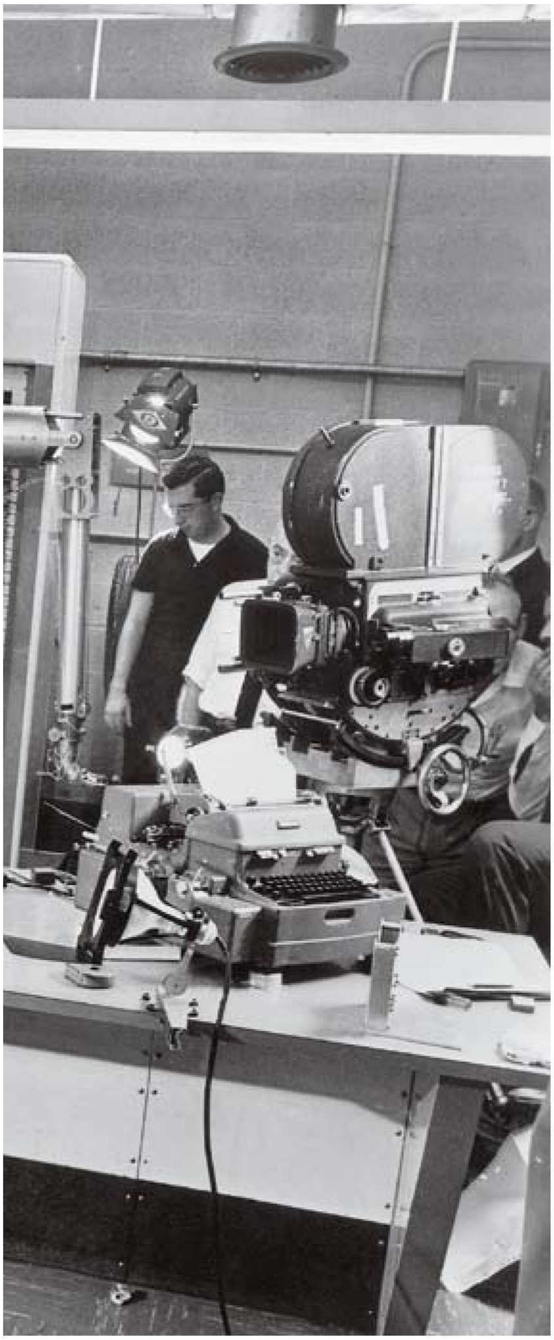
And, Lucky adds, Shannon's work inspired the development of "all our modern error-correcting codes and data-compression algorithms." In other words: no Shannon, no Napster.

Shannon's theorem explains how we can casually toss around compact discs in a way that no one would have dared with long-playing vinyl records: those error-correcting codes allow the CD player to practically eliminate noise due to scratches and fingerprints before we ever hear it. Shannon's theorem likewise explains how computer modems can transmit compressed data at tens of thousands of bits per second over ordinary, noise-ridden telephone lines. It explains how NASA scientists were able to get imagery of the planet Neptune back to Earth across three billion kilometers of interplanetary space. And it goes a long way toward explaining why the word "digital" has become synonymous with the highest possible standard in data quality.



Channeling information: Shannon explains his ideas on a 1960 CBS telecast. Such appearances were rare; Shannon shunned celebrity.

Horrified to see his theory of information being greatly oversold, Shannon dropped out of the research life.



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Switching Off

The accolades for Shannon's work were quick in coming. Warren Weaver, director of the Rockefeller Foundation's Natural Sciences Division, declared that information theory encompassed "all of the procedures by which one mind may affect another," including "not only written and oral speech, but also music, the pictorial arts, the theatre, the ballet, and in fact all human behavior." *Fortune* magazine could barely contain its enthusiasm, dubbing information theory one of man's "proudest and rarest creations, a great scientific theory which could profoundly and rapidly alter man's view of the world." Shannon himself soon had to set aside an entire room in his home just to hold all his citations, plaques and testimonials.

Within a year or two of his paper's publication, however, Shannon was horrified to find that information theory was becoming—well, popular. People were saying ridiculous things about the amount of information coming out of the sun, or even the information content of noise. Scientists were submitting grant applications that referred to "information theory" whether their proposals had anything to do with it or not. "Information theory" was becoming a buzzword, much as "artificial intelligence," "chaos" and "complexity" would in the 1980s and 1990s. And Shannon hated it. In a 1956 paper entitled "The Bandwagon," in the journal *Transactions on Information Theory*, he declared that information theory was being greatly oversold. "It has perhaps ballooned to an importance beyond its actual accomplishments," he wrote.

Rather than continue to fight what he knew was a losing battle, Shannon dropped out. Although he continued, for a time, his research on information theory, he turned down almost all the endless invitations to lecture, or to give newspaper interviews; he didn't want to be a celebrity. He likewise quit responding to much of his mail. Correspondence from major figures in science and government ended up forgotten and unanswered in a file folder he labeled "Letters I've procrastinated too long on." As the years went by, in fact, Shannon started to withdraw not just from the public eye but from the research community—an attitude that worried his colleagues at MIT, who had hired him away from Bell Labs in 1958. "He wrote beautiful papers—when he wrote," says MIT's Fano. "And he gave beautiful talks—when he gave a talk. But he hated to do it."

From time to time, Shannon did continue to publish. A notable example, before he became too horrified by his celebrity and withdrew more completely, was a seminal 1950 article for *Scientific American* describing how a computer might be programmed to play chess. But he slowly faded from the academic scene, recalls Peter Elias, another leader of the MIT information theory group. "Claude's vision of teaching was to give a series of talks on research that no one else knew about. But that pace was very demanding; in effect, he was coming up with a research paper every week." By the mid-1960s, Elias recalls, Shannon had stopped teaching.

COURTESY OF BETTY SHANNON

Funny motions: A W. C. Fields that bounced balls on a drum typified Shannon's ingenuity.

After his official retirement in 1978, at age 62, Shannon happily withdrew to his home in the Boston suburb of Winchester, MA. Money was not a concern; thanks to his knowledge of the high-tech industries springing up around Boston's Route 128, he had made some canny investments in the stock market. Nor did there seem to be any diminution of his ingenuity. "He still built things!" remembers Betty Shannon with a laugh. "One was a...figure of W. C. Fields that bounced three balls on a drumhead. It made a heck of a noise, let me tell you!"

Nonetheless, there came a time around 1985 when he and Betty began to notice certain lapses. He would go for a drive and forget how to get home. By 1992, when the Institute of Electrical and Electronics Engineers was preparing to publish his collected papers, Shannon was disturbed to realize that he couldn't remember writing many of them. And by mid-1993, with his condition becoming apparent to everyone, the family confirmed what many had begun to suspect: Claude Shannon had Alzheimer's disease. Later that year his family reluctantly placed him in a nursing home.

In 1998, when his hometown of Gaylord, MI, commemorated the 50th anniversary of information theory by unveiling a bust of its creator in a city park, Betty Shannon thanked the town in his stead. Physically, she says, he was fine almost until the end, when everything seemed to collapse at once. But on February 24, just two months shy of Shannon's 85th birthday, the end did come. "The response to his death has been overwhelming," she says. "I think it would have astounded him."

ILLUSTRATIONS BY HOLLY LINDEM

BY CHARLIE SCHMIDT

THE ROAD AHEAD

In the future of wireless traffic management, your cell phone and windshield-mounted toll tag double as traffic sensors, and your pager and onboard computer put real-time traffic reports in the driver's seat.

A LONG ROUTE 90 NEAR San Antonio, brake lights are starting to flash. Twenty-five kilometers away, Sam Mendoza is sipping coffee in the region's "TransGuide" traffic management center, where 16 wall-mounted television monitors display scenes from some of the 109 video cameras peering at 100 kilometers of area highways. Suddenly, a beeping sound signals that traffic on Route 90 has slowed below 40 kilometers per hour, as sensed by some of the 1,700-odd magnetic-loop detectors embedded in the region's roads. Mendoza seizes a computer mouse and zooms a highway-mounted camera toward the problem spot; soon his monitor reveals two bearded men in the breakdown lane struggling to fix a pickup truck's flat tire. He quickly types a keyboard command, causing an arrow on an electronic sign hanging over the right-hand lane to flash from green to yellow. The light warns drivers about the flat-fixers, hopefully allowing them to avoid an accident or maybe find a different route.

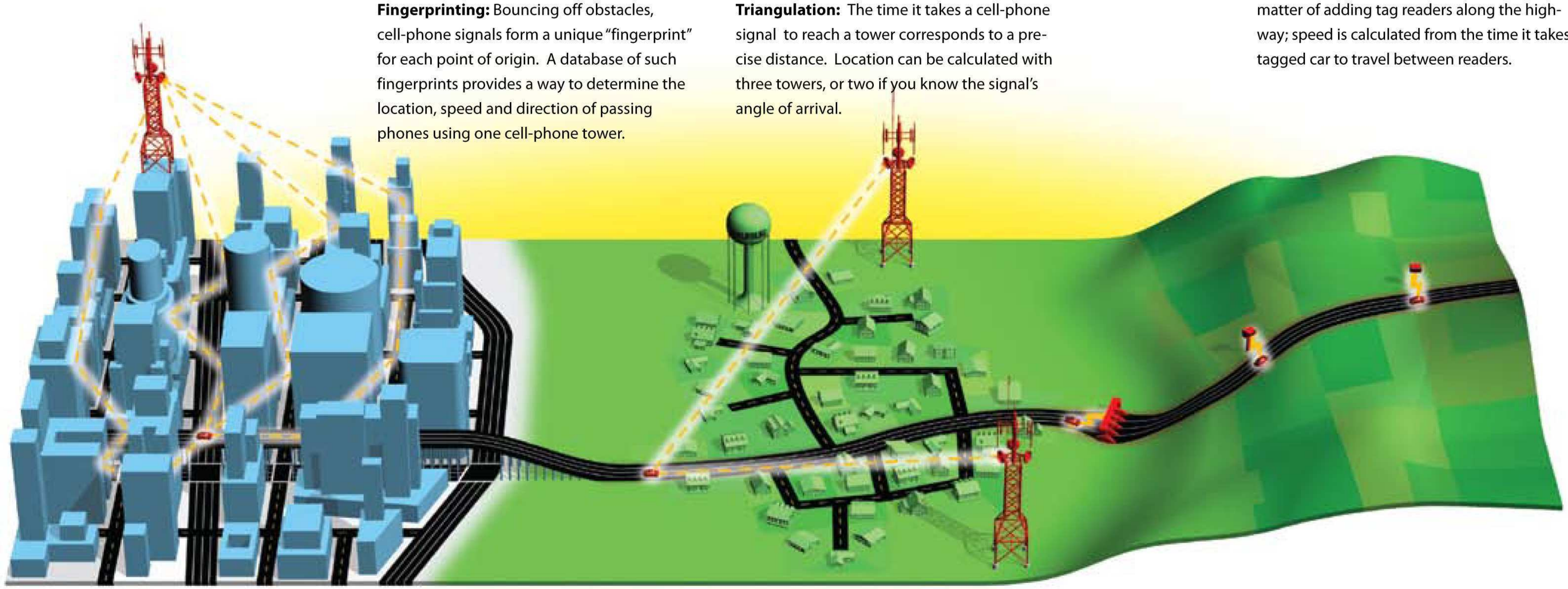
At first blush, the system at Mendoza's disposal sure looks like a smart way to fight traffic. That's what the federal government thought a decade ago when it began funding "intelligent highways," a snappy term for a laborious program of installing sensors, video cameras and programmable signs along the nation's highways. Today, systems in place in San Antonio and 49 other urban areas are indeed providing speedier accident response. But the cost is mounting, with the total taxpayer tab topping $8.5 billion to date. And despite that investment, controllers can't detect traffic beyond where the sensors are installed. Worse, they have limited ways of alerting drivers; typically it's either via signs or by notifying the news media. And as any driver knows, even a 10-minute delay until the news breaks on the radio often means it's too late to avoid the snarl.

In short, it's time to hit the brakes on Uncle Sam's approach to traffic management. Instead of a massive and costly new physical infrastructure that takes a couple decades to roll out, it turns out the road to truly intelligent highways is leading to cars themselves—or more precisely, to the wireless gadgets inside them. Tens of millions of vehicles are now loaded with cell phones, electronic toll-paying tags, onboard computers, two-way pagers and Global Positioning System receivers; all promise to play a role in a new era of wireless traffic management. That's because, as millions of drivers gab on their mobile phones, the radio signals from those devices can double as handy traffic and speed sensors. Meanwhile, devices ranging from the lowly pager to luxury navigation systems are beginning to provide ways for drivers to get real-time traffic information, customized for their routes. Even better: for-profit wireless companies seem willing to pick up part of the tab.

Plenty of curves and obstacles lurk along this new wireless superhighway. The technology needs refinement, business models remain unproven and drivers will want assurances their privacy won't be invaded by new highway listening posts. But the promise is hard to deny. Around the country, from the crowded Washington Beltway to the San Francisco Bay, incipient tests of wireless traffic sensing are already hinting that these new technologies can augment—and even eclipse—the original federal program, and do it in a matter of years, not decades. "With wireless technology, we don't have to wait for the government to install loop detectors," asserts Kenneth Orski, president of Urban Mobility, a Washington, DC-based transportation consulting firm. "Private enterprise can set up cellular networks faster and cheaper and extend intelligent highway capabilities to virtually every highway in the nation."

SLIM FILMS

Traffic Sensing with Cell Phones, Toll Tags



Fingerprinting: Bouncing off obstacles, cell-phone signals form a unique "fingerprint" for each point of origin. A database of such fingerprints provides a way to determine the location, speed and direction of passing phones using one cell-phone tower.

Triangulation: The time it takes a cell-phone signal to reach a tower corresponds to a precise distance. Location can be calculated with three towers, or two if you know the signal's angle of arrival.

Toll tags: In some regions, toll-paying radio tags are in wide use. Traffic sensing is a simple matter of adding tag readers along the highway; speed is calculated from the time it takes a tagged car to travel between readers.

EMISSIONS AND ENERVATION

New ideas for battling traffic can't come fast enough. The Federal Highway Administration estimates that U.S. drivers spend 4.3 billion agonizing hours each year stuck on clogged roads. The average American now spends 36 hours per year stuck in traffic, up from 11 hours in 1982, according to a Texas Transportation Institute study released in May. The U.S. Environmental Protection Agency says tailpipe emissions are responsible for about 58 percent of U.S. emissions of carbon monoxide, 30 percent of nitrogen oxides and 27 percent of volatile organic compounds, among other pollutants. These bleak realities prompted Congress to begin funding embedded sensor systems in 1991. But while the resulting "Intelligent Vehicle Highway Systems Program" did unleash technology against traffic, it was technology developed in the 1980s. Today, only about 10 percent of U.S. highways contain these sensors, a figure expected to increase to no more than 20 percent by 2020. Although the benefits of these systems vary by city, studies have generally shown they mostly help by speeding emergency response, with no hard proof that sensors have improved travel times.

> "We don't have to wait for the government to install loop detectors. Private enterprise can set up cellular networks faster and cheaper and extend intelligent highways nationwide."

All of which leaves the fast lane open for a wholly new approach to traffic management, one where radio waves replace magnetic loops as the key sensing technology. The clear leader of the wireless pack, experts say, is the cell phone. It was the mobile phone, after all, that first beat roadway sensors to the punch: drivers simply began calling 911 to report accidents they'd witnessed. Today, every American hillock, church steeple and high-rise seems to have sprouted a cellular radio transmitter and antenna. Americans own about 111 million cell phones—almost one for every two people—with 46,000 new subscribers every day, according to the Cellular Telecommunications & Internet Association, a trade group in Washington, DC.

Transforming this wireless communications infrastructure into a traffic-sensing tool is the next step. Radio waves emitted by a driver's cell phone during ordinary conversation can be used to pinpoint not only a car's location but its speed and direction, too. The first application will be for emergency use: the federal government is requiring that, by October 2001, cell-phone companies be able to provide precise mobile-phone location when a 911 call is made. Eventually these new location technologies could greatly extend and enhance today's intelligent-highway infrastructure, too.

The leading approach to analyzing cell-phone signals to detect traffic patterns exploits the fact that these signals have distinct "fingerprints" that change as the phone's location changes. That's because a mobile-phone signal bounces off buildings, hills and other obstacles before converging on a cell tower, producing a unique signal pattern for every spot along a roadway. Once these fingerprints are mapped and stored in a database, it's possible to create software that analyzes the signal of a passing cell phone—by sampling it several times per minute—to determine a car's exact location, direction and speed.

WIRELESS BELTWAY

Developing such a map is precisely the job of a white Ford E-150 van that regularly cruises a 30-kilometer stretch of the Washington, DC, Beltway, one of the nation's epicenters of both traffic and talk (60 percent of area residents own cell phones). The van is owned by San Ramon, CA-based U.S. Wireless, a leader in the nascent business of generating traffic information. As the van tools down a congested stretch of I-495 from Springfield, VA, to Andrews Air Force Base, MD, a passenger talks on a cell phone. Every nuance of the signal fingerprints from that conversation is captured by a network of antennas and computers the company has installed on office and industrial rooftops lining the highway.

Then, thanks to a GPS receiver system in the van, each fingerprint is matched with an exact spot on the route. Later, when cars with cell-phone-chatting occupants drive by, the U.S. Wireless computer picks up the fingerprint, finds a match from its database, and—presto—spits out a location. By gauging how the fingerprint changes over time, the system's algorithm can calculate direction and speed, too. "Wherever we set up the network, we'll be able to monitor vehicle density, speed and acceleration, and provide that information to anyone that's willing to pay us," says Howard Blank, U.S. Wireless's vice president of technology.

To help support this grand experiment in cell-phone-signal cartography, the Maryland and Virginia transportation agencies are ponying up a combined $400,000. Initial results are encouraging, says David Lovell, assistant professor of transportation engineering at the University of Maryland, who is evaluating the test for the state of Maryland. The

technology "tracks the trajectory of the vehicle continuously, which allows you to get a better feel for the pattern of congestion on the highway" than is provided by magnetic-loop sensors, he says. The test is continuing, but a report assessing its results is not due until December. Lovell says, however, that "everything appears to be working well so far."

Still, not everyone is convinced by the tests. "It's really a bizarre way to do this," says Paul Najarian, director of telecommunications at the Intelligent Transportation Society of America, a research organization based in Washington, DC. "Every time a building comes up or goes down they have to recalibrate it. And the local topography changes according to the seasons. They basically have to run their van through the coverage areas over and over again to keep it all up to date."

U.S. Wireless officials counter that recalibration costs are trivial compared to loop detector installation and maintenance. But while the company labors to perfect its technology, chief competitor TruePosition of King of Prussia, PA, is developing an alternative approach that never needs recalibration. TruePosition's scheme is based on triangulation—determining cell-phone location from the times it takes signals to reach three or more stations. By also analyzing the angle at which a signal arrives, the company can accomplish this feat using just two towers, says Matthew Ward, TruePosition's manager of strategic product development. Speed is calculated from changes in location over time, as with the U.S. Wireless technology. TruePosition is currently focusing on providing technology for 911 phone-finding. But Ward says the company plans to test its technology for traffic applications.

Beyond cell phones, there's another wireless technology already beefing up traffic reports in some areas: those increasingly common toll-paying, windshield-mounted radio tags. Normally, a special tollbooth "tag reader" senses the passing device, records the code number associated with the owner's account and subtracts the toll—and that's it. But the E-ZPass tags used by more than four million New York-area drivers now double as speed and traffic detectors.

To use the tags for this new purpose, the Transcom coalition of regional transportation agencies mounts readers at regular intervals (ranging from 0.4 to 2.4 kilometers) along a highway. By analyzing the time it takes for a tagged car to pass between the readers, special software can calculate the speed of traffic along key arteries, with the results displayed in a regional traffic-management center in Jersey City, NJ. Just as Sam Mendoza does in San Antonio, operators publicize any snarls on electronic roadside signs or by alerting the news media. By the end of this year, more than 300 kilometers of highway stretching from Hartford, CT, to Trenton, NJ, will bristle with tag readers for speed detection, with Massachusetts and Pennsylvania eyeing the idea.

Ultimately, it might be possible to complement—or even replace—this growing arsenal of sensors with a third wireless device: the GPS receiver showing up in more and more cars, mainly as a navigation aid *(see "The Commuter Computer,"* TR *June 2000)*. GPS could, in theory, provide a means of continuously tracking a vehicle's location. But although traffic planners would love to collect all those rolling position figures and squeeze the numbers for speed and traffic data, it will be hard to pull off, at least for now. That's because GPS receivers are just that—receivers, which determine position from incoming satellite signals—and don't send position data unless a driver initiates a link, as when calling police for help or looking for directions. Such calls are relatively rare compared to cell-phone chatter; besides, reading a car's position would involve eavesdropping on the content of a call rather than just sensing a signal.

TRAFFICKING IN TRAFFIC

But before these emerging traffic-management technologies can really make their mark, some critical questions remain to be answered. One of the most basic is who will pay. "The technology is available," says Najarian of the Intelligent Transportation Society. "But what's missing is a revenue flow tying all these elements together."

U.S. Wireless, for one, hopes to sell its data to state agencies, allowing them to broadcast updates via the standard news reports and warning signs, plus any future avenues that evolve. It's also a good bet that many drivers will pay at least a modest fee to save some of those 4.3 billion hours spent stuck in traffic. Cue, a pager company in Irving, CA, is already charging $10 to $15 a month for personalized traffic information in more than 60 U.S. markets. Cue collects its data from all available sources, including loop detectors, helicopter news reports and, eventually, cell-phone signals. After a customer programs a route into a two-way pager, the company sends personalized alerts. These can be read as text on the pager or heard through a voice synthesizer.

Convincing people to pay for such services means getting them very precise information in a form they can use, notes Gerald Conover, a technology manager at Ford Motor and chairman of the International Affairs Council at the Intelligent Transportation Society of America. "Say I'm in Manhattan," he says. "What I want is the real-time traffic environment on the street that I'm driving on, as well as the streets above and below me. I want the sensor data on a map so I can make instant decisions."

On this front, GPS could really strut its stuff. While GPS won't send traffic data, it might play a key role in helping drivers receive it. Using a wireless link, a driver might download real-time traffic data that an onboard computer could filter based on the car's GPS-derived position. If the news was bad, navigation software could offer alternate routes. This information could be paid for by subscription, or delivered free along with advertising (geared to location in many cases: "McDonald's at the next exit!").

> "The technology is available. What's missing is a revenue flow tying all these elements together" for expanded wireless sensing and real-time traffic reports.

But even if the right business models and communications methods are found, another concern remains: guaranteeing privacy. Drivers worry their toll tags, cell phones and other gadgets could be used to track their movements for market research, surveillance or to mete out speeding tickets, says James X. Dempsey, deputy director of the Center for Democracy & Technology, a Washington, DC-based privacy organization. "The real concern here is that the information could be compiled and used to categorize, characterize and judge people," says Dempsey.

The fears of E-ZPass owners on this front were tempered when Transcom agreed to scramble identifying information before launching the program in 1995. But the solution to the cell-phone privacy problem is somewhat less clear.

Cell-phone trackers U.S. Wireless and TruePosition insist they don't record caller identity on their networks. "We couldn't care less who the callers are," says U.S. Wireless's Howard Blank. "We use dummy identifiers like 'caller number one' and 'caller number two.'" But company promises aren't backed up by law. While telecom companies are barred from disclosing someone's identity without consent, Dempsey notes that upstarts like U.S. Wireless technically aren't telecom carriers, and so they aren't covered by such restrictions. The Cellular Communications Industry Association, a Washington, DC-based trade organization, recently proposed that the FCC develop privacy guidelines that include a provision for notifying customers of how their cell signals might be used.

Another view is that people will gladly cede some of their privacy for the chance to beat a traffic jam. Highway administrators in San Francisco, one of the first cities to explore cell-phone traffic sensing in detail, are about to put that view to the test. The region's Metropolitan Transportation Commission is poised to sign a six-year, $5.2 million contract to study whether the U.S. Wireless approach can augment the brainpower of the city's magnetic-loop-based "intelligent highways."

"We'd like to use the system to develop highway speed profiles that drivers could use," says Michael Berman, project manager with the Bay Area commission. First, though, they're convening focus groups and conducting surveys on the privacy question.

Will the public accept it? That's an open question. But has the technology arrived to lead traffic management into the wireless age? That call has already been made. TR

Wireless World of Traffic

Wireless traffic management is taking hold worldwide with a range of sensing and communications technologies—even ways to charge higher tolls at rush hour. A few strategies:

COUNTRY	PROGRAM NAME	MAIN SENSING TECHNOLOGY	GETTING INFORMATION TO DRIVERS
Japan and Communication digital maps	Vehicle Information in road surface	Magnetic-loop detectors information displayed on dashboard	Roadside microwave/infrared beacons; System
France	Visionaute	Magnetic-loop detectors; cameras and aerial surveillance times displayed on dashboard maps	Dedicated radio receiver accesses traffic information; estimated travel
U.K.	Trafficmaster	Infrared sensors at regular intervals track license plate numbers for traffic speed sensing	Broadcast via radio frequencies; dashboard maps display traffic speeds and delay times on highways
Singapore	Electronic Road Pricing Scheme	Tag readers sense toll tags on passing cars, charge higher tolls at rush-hour times	None directly to cars; drivers billed for tolls

Q & A

DIRECT FROM DELL

MICHAEL DELL CALLS HIMSELF AN "AGITATOR FOR PROGRESS." NOW HE'S READY TO TAKE ON HP, SUN, EMC AND CISCO. PHOTOGRAPHS BY WYATT MCSPADDEN

EVEN IN THIS ERA OF BUSINESS PRODIGIES, HIS YOUTHFUL SUCCESS IS VIRtually unrivaled. Michael Dell recently turned 36 years old, and already he's considered a sage on matters of business and technology. Dell Computer, which he founded at age 19, was the best-performing American stock of the 1990s. Long the front-runner in U.S. personal computing sales, the company took the global lead from Compaq in the first quarter of 2001—and with $32 billion in revenues last year, it's bigger than Microsoft.

So how do you build the world's largest PC company? Dell points to such old-fashioned strategies as giving people what they want and for a lower price; for that reason, he admires the work of Henry Ford and Wal-Mart's Sam Walton. But he also revolutionized the selling of personal computers, using a direct-business model whose fundamental tenets include taking custom orders directly from customers, thereby reducing inventory and streamlining distribution. That model rocked the world of competitors like IBM, Compaq Computer and Apple Computer and changed forever the economics of the business.

Despite such accomplishments, Dell's chairman and CEO remains focused on the next big thing. Recently, with PC sales growth slowing, he moved into storage and Internet servers—taking on the likes of Hewlett-Packard, Sun Microsystems, EMC and Cisco Systems. *Technology Review* editor at large Robert Buderi met Dell at his Austin, TX, headquarters and asked about the company's brilliant legacy of growth, the "pragmatic" R&D intended to keep the flame burning, the future of computing and his hopes for the now slumping economy that this year has seen his firm endure its first layoffs—between 4,700 and 5,700 jobs, more than 10 percent of its work force.

TR: People get damned and praised for the wrong reasons sometimes. What do you feel you've done as an innovator—and what's been misunderstood?

DELL: People look at Dell and they see the customer-facing aspects of the direct-business model, the one-to-one relationships. What is not really understood is that behind these relationships lies the entire value chain: invention, development, design, manufacturing, logistics, service, delivery, sales. The value created for our customers is a function of integrating all those things.

If you go back to the dot-com craze of a year or two ago, a lot of people were saying, "Oh, we know how we're going to succeed—we'll create a Web site just like dell.com, and we'll be the Dell of the whatever industry." The problem with that is that Dell's business is not a Web site. While we do half our business on the Web, it's just the front end to this business system. Dell has filed well over a thousand patents, we have four or five thousand engineers, and we spend $700 million in R&D. And we're always asking ourselves, "How can we optimize the set of conditions we're faced with—whether it's supply chain, customer relationships, time, speed or cost?"

Remember that the computer industry when Dell entered it had gross margins of 40 percent plus. On top of that, you had dealers with margins of 20 to 30 percent. So the end user was paying a pretty incredible premium over the cost of goods for the product. And then Dell came along, and I fully acknowledge if it hadn't been Dell it would have been somebody else, and the industry gross margins have gone down quite dramatically. Which means that parts are far more affordable, which means that the industry has grown a whole lot faster than it ever could have, which means that people have greater and faster access to technology. And I believe fundamentally the market grew faster because we forced a condition to exist—and businesses that didn't add value were forced to move on.

TR: What's the hype in computing, and what is real? Is the PC dead?

DELL: The industry tends to get fascinated with new concepts and ideas—and one of the biggest problems we see is technology in search of a problem. Take a very contemporary example. Bill Gates has been talking about tablet computers [portable devices with, ideally, the simplicity of a Palm Pilot but the computing power of a laptop—and between the two in size]. Now, maybe tablet computers will be successful this year or next year, maybe they won't. But the idea of a tablet computer is not new. The pen computer industry was here 10 years ago, and there were trade shows and companies specifi-cally created for that. Didn't work, wasn't ready.

It's a great example of technology push instead of customer pull. Another good example is the Internet appliance, which captured a lot of attention about a year ago. And here again, you had this fascination with something that's new—sounds like a good idea, but maybe isn't. So when you go back and look at the bone pile of things that might have been—the "almost famous" category of technologies—it's a pretty big mess.

And that's why we embrace this philosophy of time to volume. At Dell, we invest only in technology our customers want, rather than trying to guess what they might want. And we only manufacture what our customers ask us to make, when they ask us. Dell has five days of inventory, while at HP, they have 63 days of inventory. They also have something called a distribution channel. This is when you go to CompUSA and you look on the shelf and see all the computers stacked up. Those are monuments to the failed forecasts of what you didn't want to buy. And in the distribution channel, there's another 25 to 30 days of inventory, so you add that to the 63, and you get 85, 90 days of inventory compared to our five.

Now, what that means, first of all, is a time-to-market advantage. I can get you the freshest, latest, greatest Pentium 4 and all associated operating system, et cetera, 85 days faster than HP. It's also a massive economic advantage, because the value of components and manufacturing materials declines about one percent per week. So the net of this is they're all screwed up.

The other problem with a long feedback loop is the distortion in the signal. If you tell me what you want to buy and I hear it 90 days later, by the time I get the signal you want something else. This is another area where our business model has a big advantage.

TR: Still, PC sales have been slowing—increasing the need to find new growth areas. What was it that attracted you to servers and storage?

DELL: About five or six years ago, we saw that the application world was becoming increasingly server-centric—we couldn't have anticipated Internet-centric, but that's where it was ultimately going—and that more and more of the profit was shifting from the client [the PC] to the server. We also saw that our competitors, most notably at the time Compaq, were dramatically overcharging customers for those products.

"THERE'S NOTHING ABOUT STORAGE OR INTERNET-SERVER PRODUCTS AND TECHNOLOGIES THAT SCARES US."

TR: The same thing you'd seen in PCs?

DELL: Same phenomenon. Five years ago we had two percent market share in the U.S. server market; Compaq had 44 percent. Last quarter [the fiscal quarter that ended Jan. 31, 2001] we had 22 percent, and they had 26 percent. We're growing four and a half times faster than the market, while they're shrinking. Soon we'll pass Compaq in the United States [this spring, Gartner Dataquest reported that

Dell had indeed surpassed its rival in the U.S. server market], and at this point our U.S. server business is more than four times larger than HP's. So we've just gone in totally opposite directions from our competitors.

What we see in storage, with our friends at EMC, is the same thing all over again. There's more of a software component to storage—in the management of large volumes and the virtualization of different logical units of storage across a wide variety of heterogeneous server platforms. But there's nothing about those products or technologies that scares us. The industry keeps moving towards broad standards, and that creates a real dilemma for companies who try to create and lead an industry by maintaining proprietary platforms and high margins.

The unmistakable trend here is that industry or open standards are beneficial to customers. If you look at any proprietary computer company in history, whether it's Silicon Graphics, Data General, Digital, Prime or fill in the blank, the fate is almost always the same. Their higher margins make them a prime target for nonproprietary competitors. Because in an industry or open-standards environment, companies can focus on what they're good at and not spend resources on what they're not. So innovation is high, and costs are low—and this is the challenge a lot of these companies have.

Our business model is in many ways the polar opposite of the proprietary computing model. If our margins are going up, we get worried, and we wonder whether we're doing everything we can to deliver more value to our customers. Because if we're not, we know somebody else will.

TR: What do you think is the real role of the Internet in our economy today?

DELL: At the root of any economic system is the cost of transactions. You have something you want to sell, I want to buy it, and what that transaction ultimately costs is tied to the cost of communicating information. The Internet is the latest evolution of communication technology—tremendously powerful because it enhances the flow of information. So basically it's like a big vacuum that sucks friction out of the economy.

And there are a number of businesses that may have existed in the past on the idea that the customer has somewhat limited information, so they're going to buy their product. In other words, you live in a small town. The customer has no other ways to get it, that's the price. You don't have a choice. You can't really fly to

another city and get it, that's not practical. You don't have other sources of information. Now all that's changing. So the Internet can help those companies that thrive on information, like a Dell. Businesses that don't thrive on information, that thrive on lack of information, they're in danger.

TR: Dell's R&D expenditures, about $700 million, are small compared to Microsoft's $4 billion. They're also only about 2.5 percent of revenues—minuscule for high-tech firms. Do you worry you're not investing enough?
DELL: It's not like the nuclear-arms race. We have to pick the amount that's appropriate for what we want to do. Could we spend $1.75 billion? Absolutely. Could we spend $2.75 billion? Even easier. We could spend $5 billion on R&D. But the harder question is, Where is your point of diminishing returns? In a typical, classical development world, you'd say, well, we're just going to tie this thing to the revenue, which I contend is really nuts. And so what we don't do here is say, "Revenues are going to be $40 billion, and five percent of $40 billion is $2 billion, so let's figure out how to spend $2 billion on R&D."

Instead we say, "Okay, we want to have these eight-way servers. We're going to have these storage programs. We're going to have a full lineup of notebooks and desktops and workstations. We're going to have these software management tools. What will it cost us to do all this?" And if that number is $842 million, then that's the budget. And if we add three things and it goes up to $860 million, or we take out four things and it goes to $820 million, that's the budget.

As for comparing Dell to Microsoft, it doesn't give you the full picture. Microsoft is our partner, and we leverage the R&D work they're doing in operating systems.

TR: So you're actually getting the benefit of their R&D. You're piggybacking?
DELL: Exactly. If you look at the original orientation of the industry, each computer company tried to do everything itself—its own silicon, processors, operating system, power supplies. Digital was in the business of making power supplies up until three or four years ago. Now, you say, why do you want to design power supplies? Well, maybe it's fun, or maybe it's what we did last year—or maybe we just think we're better than anybody else. Maybe we got this disease called Not Invented Here.

This is the problem a lot of companies got into. Our approach is more pragmatic: if we can buy something that's very similar to something we can create ourselves, we believe it might not be valuable for us to create it. On the other hand, if we're thinking about creating something that nobody else has, that's worth doing. And I can point to hundreds of unique inventions or ideas that we have driven. We had the first color notebook that was powered by batteries. We had the first 486 machine to ship. We had the first system to ship with the EISA [Extended Industry-Standard Architecture] bus. Right now our notebook team is continuing to drive very, very hard on size, weight, wireless integration—we were the first to integrate wireless into notebooks, with integrated antennas.

TR: Do you have a central research lab? Also, about two years ago, you started Dell Ventures, which makes strategic investments in startups and other firms. Where does that fit into this broader picture of how you assemble research?
DELL: We've always had some small group that has done research. It's gotten to be a formal organization in the last couple of years—a Dell Labs group. But it's not a huge group. Their role is to think beyond the product road maps, which end between 18 months and two years out. They also have a technology council, where we review key promising areas and determine whether we should continue research in those, or whether we should skip them and learn something else. And they do quite a bit of experimentation with things. So they're off playing around with handhelds and wireless and voice, you name it.

Dell Ventures can also play a significant role in pioneering and testing new concepts, new technologies, new ideas. For us, Dell is not an ingredient company; we're a systems company. We provide solutions to our customers. So, take batteries as an example. We don't have any factories that make batteries. We don't have any plans to make them. But we know where all the batteries are made. We consume 20-plus percent of the worldwide production of batteries that go into products like ours and have some very small number of people who understand the chemistries that go into batteries. And if we felt that the industry wasn't investing enough, battery development would become an issue for us.

But, instead, we see a lot of experimentation. And when we see, for example, one company with a lot of production capabilities and another with a lot of technology, we put them together. We just did this with a CRT [cathode-ray tube] innovation. We found a company that had a semiconductor replacement that offered smaller size, longer life, reduced cost, better focus and lower voltage levels than the cathode we'd been using. We invested in the company, and we hooked them up with our CRT providers to get this thing designed in. We don't want to buy the company. Why buy the cow when all you want is the milk? We'll take a piece of that company, make sure that invention gets into our products, and probably our products first, so we get some differential advantage—and go on and look for the next one.

TR: What has you most excited about the future of computing?
DELL: A lot of the things we've done at Dell, in terms of supply chain and collaboration and information flow—integrating these kinds of systems—has helped to democratize the market by bringing down prices. Owning a personal computer is now widely accessible.

But the industry is really very much in its infancy. We still have a long way to go in terms of improving our products and making them easier to use. In the future it's going to be easier to connect disparate systems together and get to the next level of productivity—and that's very, very exciting. There will always be big, underpenetrated markets just looking for improved productivity, regardless of economic conditions. So I have lots of optimism for productivity in the future.

I'm also excited about wireless Internet access. We live in a mobile world. People are constantly on the move, but their fundamental needs don't go away when they leave their homes or offices. They want to stay productive, and they want to keep in touch. Wireless technology lets them do that.

TR: What's the biggest lesson you've learned about innovation?
DELL: To encourage it and allow it to happen. If you try to do it all from the center of the company, it doesn't work. You have to break things down into focused units that have clear objectives, so everyone in the company is driving to innovate within their particular customer area. We have to carefully decide how we're going to allocate our resources. And we have to allow for a measure of experimentation. When you stop experimenting, you're dead—because then you have no ideas, you have no breakthrough thinking.

A couple of years ago, one of our teams came in and said, we got this idea—just bear with us a second—we want to take a 15-inch LCD [liquid crystal display] screen and put it in a notebook computer. I said, "What are you talking about? That's not a notebook, that's a portable desktop." They said, "No, no, this will be a high-end notebook, and it's going to be 10 percent of the market." Well, it was risky, both in technological terms and market acceptance. Would the product be too heavy? Did our customers really want a large screen on a notebook? But we took the risk, and the idea turned out to be a huge success. We have plenty of examples where we've innovated and failed, but we have more where we've succeeded.

TR: What's your personal role in all this?
DELL: When I see things that I think are important, I'll push on—with wireless, say, and also by nurturing things when they're in the skunk works stage and don't necessarily have the organization's full support.

I'm the agitator for progress and change. TR

"IF OUR MARGINS ARE GOING UP, WE GET WORRIED, AND WE WONDER WHETHER WE'RE DOING EVERYTHING WE CAN FOR OUR CUSTOMERS."

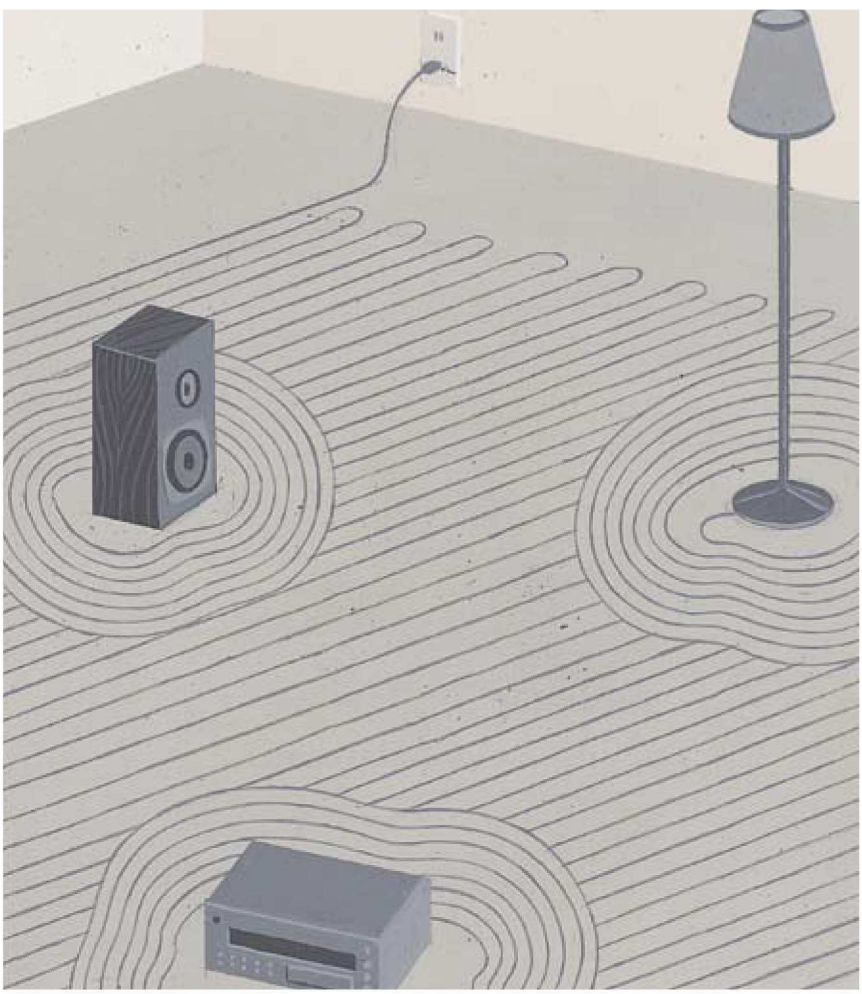
Join an online discussion of this article at www.technologyreview.com/forums/info

Edifice Complex

IS THERE A FUTURE FOR THE smart house? When, already? And what will it entail? Beyond plumbing and electricity, surely our homes will develop an "inner" net—networked intelligence to manage things more sensibly. Our buildings need to become wiser. Remember, Jane Jetson will be born someday soon, so we've got to come up with something more interesting than an Internet toaster.

A look to the past might help. I write this in Kyoto at its cherry blossom peak. Kyoto is a special city, with many ancient wooden buildings intact and in harmony with the newer city. And there is more than charm to the old homes and country inns; centuries of zenlike wisdom are infused into the architecture. Wandering through a garden, I noticed peculiar cedar trees that grew into perfectly straight poles 10 meters high with leafy pompoms on the top, like something Dr. Seuss would have drawn. This was not natural. Thousands of years ago, monks figured out that if a tree's horizontal limbs were constantly trimmed, it would grow perfectly straight. Over hundreds and perhaps thousands of years, they cultivated forests in this way to supply perfect pillars and timbers for buildings.

That kind of deep value, spanning generations, hardly applies to intelligence technologies yet. There is no zen in my tangled stereo system, or the appliances and early-20th-century heating and lighting systems that clutter our abodes. Home computers haven't helped. Technology at home is not a symphony. It's a cacophony.



NICK DEWAR

We have the ability to do better—to build dwellings that are comfortable, beautiful, functional and environmentally friendly. The difficulties are not primarily technical. They are cultural. Fly over the United States and look out the plane window: you could convince yourself that the profession of architect doesn't really exist. And the patterns of suburbs don't look much better on the ground. Common sense in design is in uncommonly short supply.

Just look at plumbing. Frank Gehry likes to call architecture "sculpture with plumbing." Great civilizations don't grow without good plumbing.

You may have heard of Ephesus, whose ruins overlook the Turkish Aegean coast. Built in the time of Christ, it is a dazzling city with marble-colonnaded streets, a massive amphitheater, a magnificent library—and great plumbing. Ephesus's Roman rulers took bathing and plumbing seriously, and some of the terra cotta sewers and pipes still work. Ephesian baths had ingenious heating systems to feed hot, warm and cold pools. Walk into the beautiful Roman latrines. You instantly admire the contoured potty seats, the rivulets underneath to carry waste away, the water channel by your feet for washing hands and toes, and the breathtaking view. Compared to my lousy little bathroom in Cambridge, it was a dream.

But go back to the nearby "modern" Turkish town of Kusadasi to use a public restroom and be horrified. To call it a hole in the floor would be generous. It's as if more than 2,000 years of better living through plumbing had never happened.

Most of the world still has very bad plumbing, where the distinction between the water to wash with and the water to drink has not yet been realized. Diseases related to impure water are among the top three causes of death in

parts of India and Asia. Management of fresh water is a significant world issue, but few homes or communities do it well, let alone with joy or ingenuity. There are of course creative solutions. Pennsylvania State University's Center for Sustainability, for example, devised a small greenhouse full of plants and snails that can thoroughly rid domestic wastewater of toxins; they call it a "Living Machine."

Even small changes in consumer behavior would have prevented the California blackouts. But bad habits are hard to break. This is where smarter use of technology in architecture might serve us well.

Worse than water is the wanton use of electricity. Whether you're at home or not, the typical electricity-guzzling U.S. house chugs away, burning power. It's too dumb to know whether you're in or out, awake or asleep. When it comes to saving power, a million-dollar home is dumber than the dumbest thousand-dollar laptop.

The United States, with less than five percent of the world's people, produces a quarter of the world's air pollution. And the number one cause of air pollution is: generating electrical power. More than half of U.S. electricity comes from burning coal, which dumps greenhouse gases into the atmosphere. Bill Browning of the Rocky Mountain Institute estimates that buildings account for more than one-third of U.S. electric power demand. More than one-fourth of that energy goes into lighting.

You don't need to be the brightest bulb on the tree to realize that energy-efficient lights, architectures that make better use of daylight and sensible approaches overall (like homes and offices that are smart enough to turn off the lights when the occupants leave) could reduce consumption enormously. Incandescent bulbs, once a bright idea, are obsolete yet still in heavy use. They are horribly wasteful: 90 percent of the electricity they draw goes out as heat rather than light. Compact fluorescent lights that fit standard sockets are four times as efficient and last 12 times as long. Efficiencies and savings with the use of new light-emitting diode technologies are likely to be even greater *(see "LEDs Light the Future,"* TR *September/October 2000).*

As power companies in California suffer under the load and embarrassingly brown out large parts of the state, it is hard not to wonder why people still design and use such dumb lighting systems. Why are incandescent bulbs used in the vast majority of homes? Are consumers so unaware? (Yes.) Does the high initial price of a compact fluorescent obscure the long-term benefits? (Yes.)

But there is a more insidious factor: force of habit. Even small changes in consumer behavior would have easily prevented the California blackouts. But bad habits are hard to break—and the Bush administration's hostility toward energy conservation isn't helpful. This is where smarter use of technology in architecture might serve us well. Unfortunately, most people tend to live with what they've got. Renters have no incentive to upgrade their homes. Homeowners find they've inherited a big box full of leaky pipes and running toilets and drafty windows and bad insulation that they don't have time or money to fix. Even when design solutions exist, it's been difficult for homeowners to obtain them. But the solutions are out there.

Carrier makes Web-enabled thermostats that can be monitored and controlled remotely, and programmed to follow set temperature patterns. That's a first step in building a home that can relax and go to sleep when you're away. An Italian company, called Wr@p, is pioneering the development of smart, networked appliances that can take turns drawing electricity to minimize peak-hour consumption.

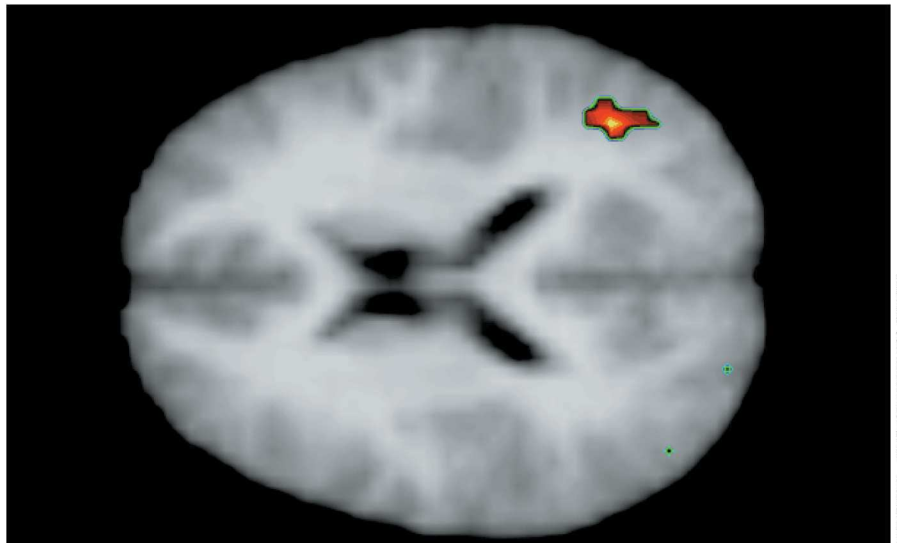
Efficiencies extend into appliances themselves. For instance, when you open and close the refrigerator door around mealtimes, your fridge goes into a tizzy as its control system fights to maintain a steady cool temperature. A smarter refrigerator (a few exist) tracks the opening and closing of the door and knows enough to sit quietly and sweat it out during periods of use. After things have quieted down, it calmly brings the temperature back under control without wasted effort—cutting energy consumption in half. That's significant: the fridge typically accounts for about one-fifth of a home's electric bill.

Whether they are within an appliance or across a household network, when your home computer is able to manage your home, efficiencies could compound into synergies. If that happens, the home could begin to counteract some of the consumer's sloppy, lazy behavior.

In design, too, behavior is still the root of the problem. Although most forward-thinking architects envision homes with sensible systems, many people feel that home architecture is for the wealthy. Substantially redesigning a home has been beyond the means of most. But an MIT research team called the House_*n* project would give consumers access to intelligent architectural design and to the gamut of other building services that have been manageable only by teams of architects and contractors. The researchers argue that such services are increasingly online, available to all who would like their homes to work better.

Commodity, firmness and delight: those are the three ideals of virtuous architecture espoused by Vitruvius more than 2,000 years ago—as engraved on the Pritzker Prize, in Henry Wotton's 1624 translation. It was, after all, the Romans who put the "arch" in "architecture," and their values have not faded. Vitruvius's order was *firmitas* (buildings should be sturdy, structurally sound shelters), *utilitas* (they should accommodate human needs) and *venustas* (like Venus, they should be beautiful). To which we could add: *sensitas.* Buildings should be sensitive, even wise. Architecture is destined to absorb intelligent technologies, and buildings ought to be smart enough to do the right thing on behalf of their residents. TR

VISUALIZE



A functional magnetic resonance image shows where brain activity occurs during some kinds of perception.

ADAPTED FROM ZACKS ET AL., *NATURE NEUROSCIENCE* 4(5), JUNE 2001

Functional MRI

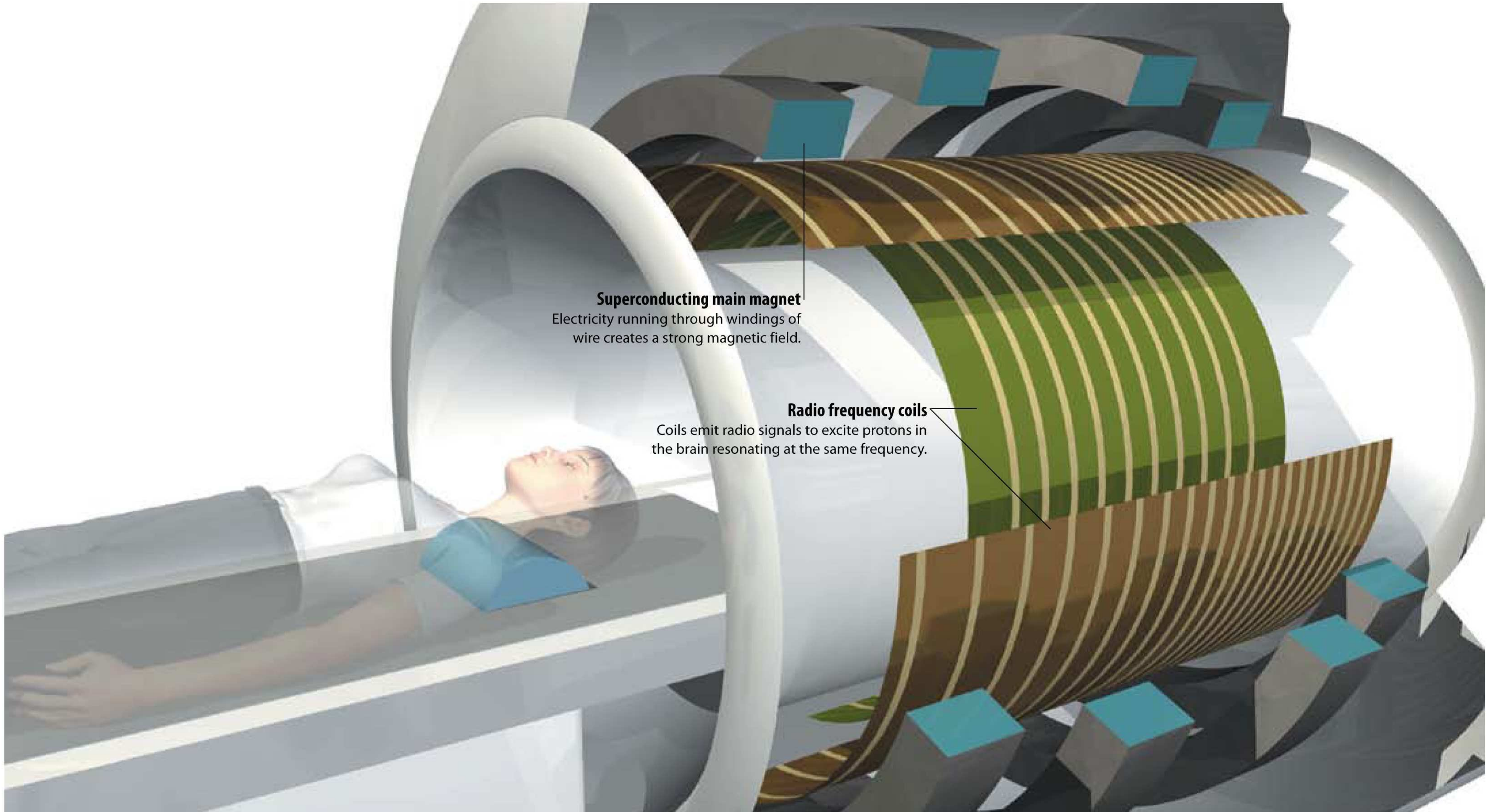
A magnet and radio signals detect brain activity

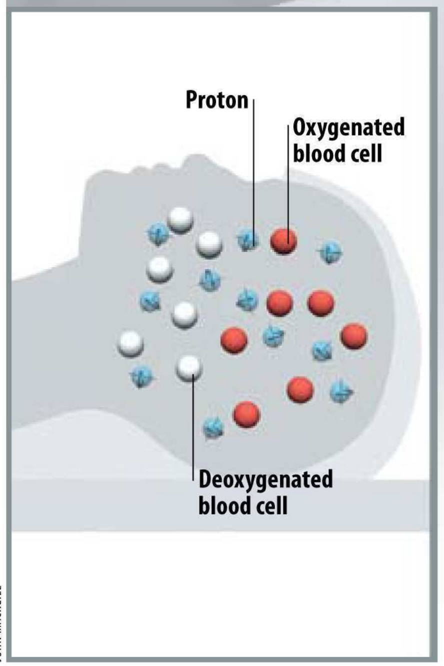
MEDICAL IMAGING HAS COME A LONG WAY SINCE 1895, WHEN GERMAN physicist Wilhelm Conrad Röntgen observed strange flickers cast by his cathode-ray instruments. Within months, Röntgen had used the mysterious "x-rays," as he called them, to produce an image of the bones of his wife's hand, revolutionizing medicine. For the first time, physicians could peek inside the body without cutting it open or probing an orifice. Today they can practically image our thoughts.

One of the latest technologies for seeing under our skin—functional magnetic resonance imaging (fMRI)—uses the combination of a powerful magnet and radio frequency pulses to see which parts of the brain are active. Neurons themselves are too small to image, but their activity causes changes in the flow of oxygenated and deoxygenated blood around them. For example, when you hear a loud noise, a patch of neurons fires on each side of your brain. Their activity requires an increase in blood supply. The oxygen-rich inrushing blood has different magnetic properties than the deoxygenated blood that it displaces. The magnet and the radio signals inside the functional MRI scanner work together to reveal where blood is rich in oxygen and where it is not. The resulting image shows the two patches of neural activity as bright regions on either side of the brain. From such maps, researchers can determine which parts of the brain are used for speech, vision, auditory and motor skills, and more.

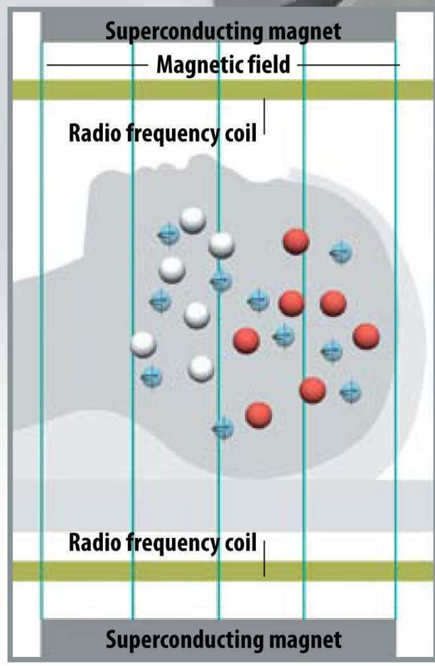
Functional magnetic resonance imaging was first realized in 1990 when Seiji Ogawa, working at what was then AT&T's Bell Laboratories, announced that he could use the contrasts in blood oxygen levels to create images of regional brain activity. The technique is a step up from diagnostic magnetic resonance, which has been around since the 1970s and produces detailed views of bones, ligaments and other tissue. Another method, called positron emission tomography, does provide images similar to a functional MRI's—but it requires patients to be injected with radioactive substances.

As fMRI improves, so too will medicine. Recently, researchers at the Medical College of Wisconsin in Milwaukee used the technology to figure out which part of the brain manages our perception of time. Their find could lead to new drugs for patients with Parkinson's disease, who often experience problems with time perception. TR

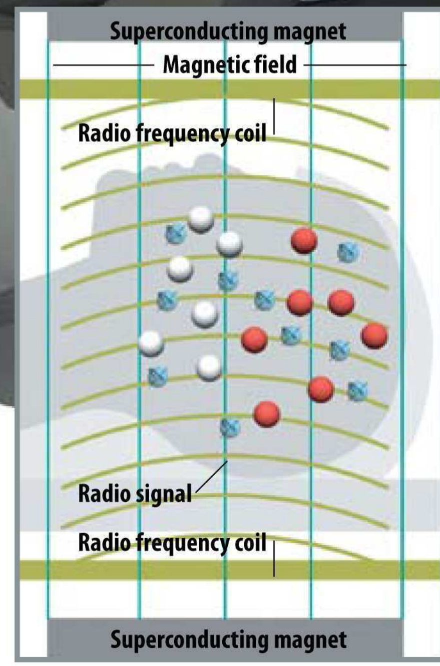




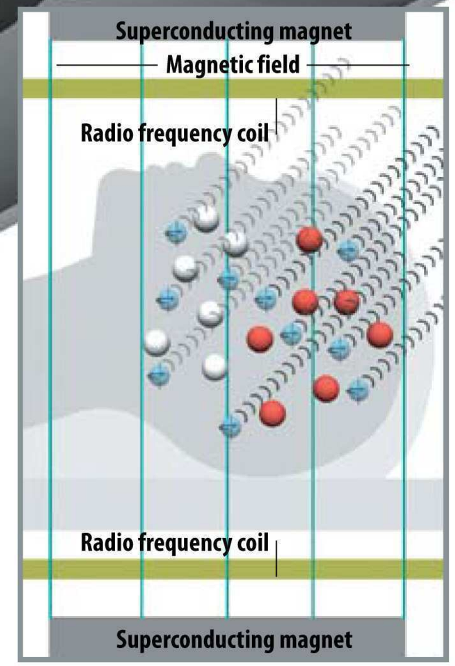
Under normal conditions, positively charged particles, or protons (blue), spin in random directions.



Inside the scanner, a superconducting magnet exudes a powerful magnetic field, which forces protons into alignment.

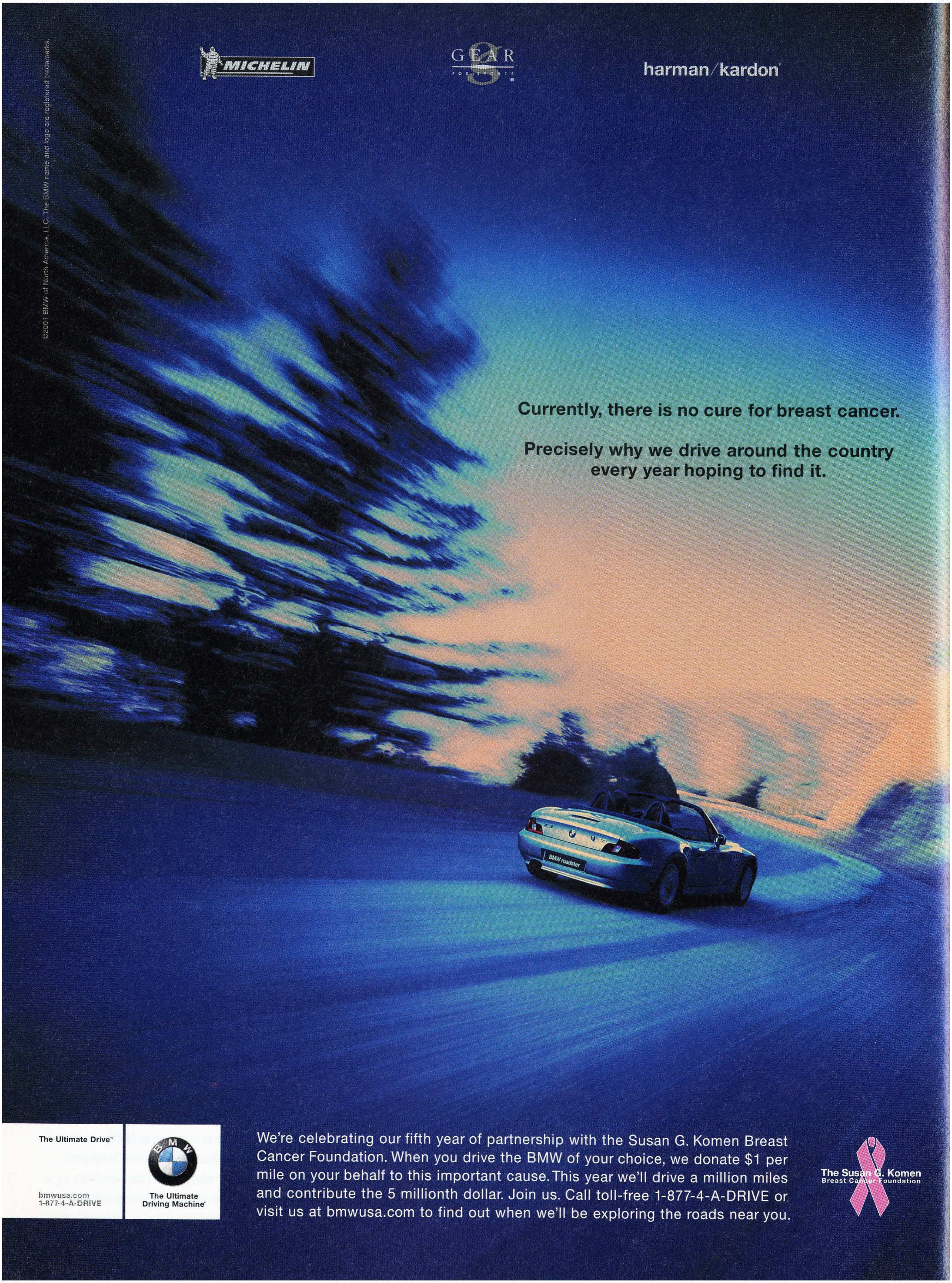


A radio frequency coil then emits short signal bursts, which temporarily knock the protons out of alignment.



After the burst, the protons snap back into alignment and emit a signal. The signal is strongest from protons near oxygenated blood, which causes less electromagnetic interference than deoxygenated blood.

JOHN MACNEILL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Culture Goes Global

POUNDING DRUMS, THROATY voices and electronic pulses rock my CD player. I have entered the world of Oceania, a remarkable musical collaboration between Maori poet and singer Hinewehi Mohi and Jaz Coleman, lead singer of the British post-punk band Killing Joke. Although Mohi characterizes the Maori as "precious feathers" blown about by global forces, her music, which sets traditional chants to a techno soundtrack, celebrates their ability to surf the winds of change.

We often imagine peoples like the Maori as existing pristine and timeless, within a display case at a natural-history museum. Yet cultures have never remained static or isolated; even in ancient times, war, trade and migration made their marks. Now, rapid transportation and global communication and commerce accelerate change. The anthropologist Renata Rosaldo compares the high-speed transformations of cultures to a garage sale, where "cultural artifacts flow between unlikely places, and nothing is sacred, permanent or sealed off." We need to recognize the richness, diversity and creativity of this garage-sale culture. Hinewehi Mohi sings in her people's traditional language, yet to a techno beat, enabling her songs to escape national boundaries and enter the global marketplace.

For decades, critics have depicted the international circulation of American goods as cultural imperialism. The United States, for example, produces nine of the top ten box office films screened in Europe each year, undercutting local culture industries. Living off their domestic grosses, the big studios can offer lower rates, maintain higher production values and spend more on marketing than local competition, while the American market remains largely closed to imports.

Those days are numbered. We are no longer the world's only powerful media-producing nation. African consumers are more apt to be fans of Hindi musicals than MTV. And even American childhood has increasingly been shaped by Asian cultural imports. Most parents now know about the Power Rangers, Tamagotchi and Pokémon, Sega and Nintendo. For the moment, English remains cyberspace's dominant language, and having Web access often means that Third-World youth have greater exposure to American popular culture. Yet these same technologies enable Balkan students studying in the United States to hear webcast news and music from Serbia or Bosnia. Thanks to broadband communication, foreign media producers will distribute films and television programs directly to American consumers without having to pass by U.S. gatekeepers.

The days when American cultural goods dominate the international scene are numbered. From music to movies, we're entering a new era of global fusion.

And they may be assisted in their conquest of the U.S. market by American teens who have developed more cosmopolitan tastes through travel or online chatting. Some fans now teach themselves Japanese in order to do grass-roots translation and subtitling of animated films (anime) or comics (manga). They scan Japanese television guides for hot properties and post their own ratings to help parents filter the often mature content. These fans have become key niche marketers, promoting U.S. awareness and acceptance of Asian popular culture.

For signs of this coming cultural revolution, look in the world-music section of your local record shop. The lower production costs and smaller shelf-space requirements of CDs have dramatically expanded the diversity of today's music store. Older consumers may find this totally alien. But contemporary college students now sample the once-exotic sounds of African pennywhistle, Tuvian throat singing or Scandinavian mandolin as casually as they choose between tacos, pizza and sushi. Seeking broader circulation, non-Western artists like Mohi often attach themselves to trends inspired by American artists. Madonna's *Ray of Light*, for example, borrowed from bhangra, an Indian-inflected dance music that previously circulated mainly on dub tapes in ethnic grocery stores. Through such exchanges, global music enters the mainstream.

In some cases, international performers return to their musical roots, appealing to the nostalgia of their country folk now scattered worldwide. Yet just as often, they mix and match once-distinctive styles to create music unlike anything we've heard. Sheila Chandra's aptly titled *Weaving My Ancestors' Voices*, for example, fuses Indian and Celtic traditions. These hybrid sounds express the experience of "third-culture" youths who may be of mixed racial, national or linguistic backgrounds, and who have spent their early years moving between countries.

Some fear that globalization will destroy cultural diversity, resulting in a world ruled by American exports. Yet the world-music scene suggests an alternative, where global popular culture enters our marketplace with help from American youth, audiences demand new forms of diversity and performers fuse traditions to create novel forms that express a widespread experience of dislocation. Call it global fusion, the Third World's answer to Walt Disney and Coca-Cola.

ESSAY | RICHARD MANNING

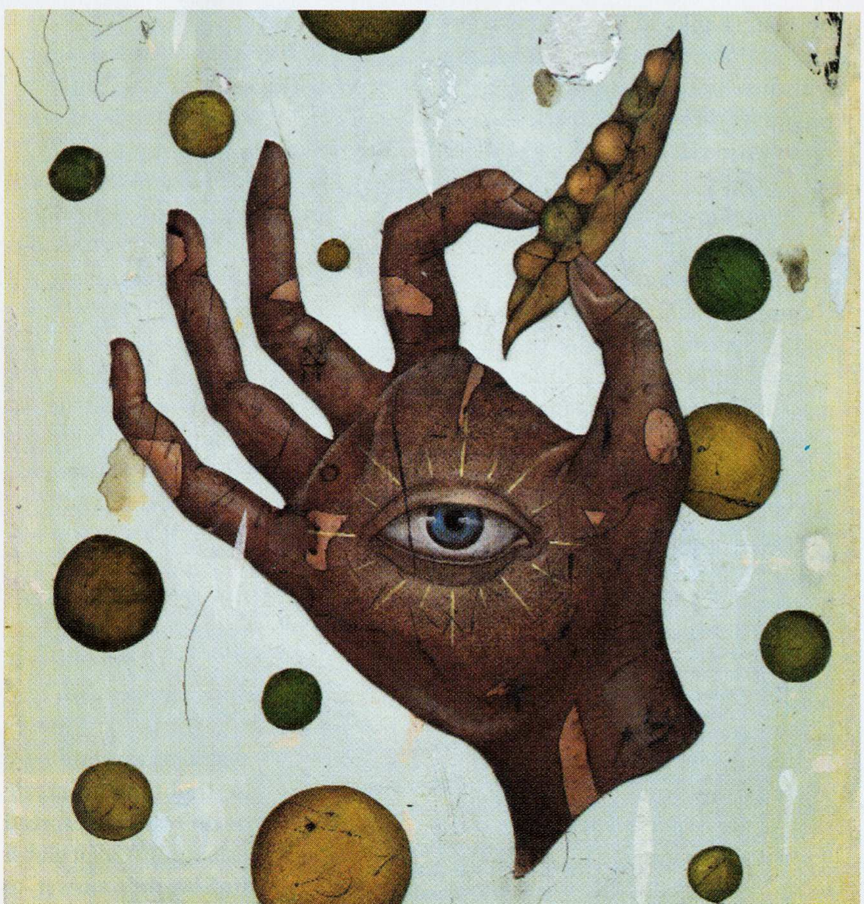
Eating the Genes

What the Green Revolution did for grain, biotechnology may do for protein

FEARS THAT GENETICALLY ENGINEERED foods will damage the environment have fueled controversy in the developed world. The debate looks very different when framed not by corporations and food activists but by three middle-aged women in saris working in a Spartan lab in Pune, India. The three, each with a doctoral degree and a full career in biological research, are studying the genes of chickpeas, but they begin their conversation by speaking of suicides.

The villain in their discussion is an insidious little worm, a pod borer, which makes its way unseen into the ripening chickpea pods and eats the peas. It comes every year, laying waste to some fields while sparing others. Subsistence farmers expecting a bumper crop instead find the fat pods hollow at harvest. Dozens will then kill themselves rather than face the looming hunger of their families. So while the battle wages over "frankenfood" in the well-fed countries of the world, here in this Pune lab the arguments quietly disappear.

A generation ago the world faced starvation, and India served as the poster child for the coming plague, occupying roughly the same position in international consciousness then that sub-Saharan Africa does today. The Green Revolution of the 1960s changed all that, with massive increases in grain production, especially in India, a country that now produces enough wheat, rice, sorghum and maize to feed its people. Green Revolution methods, however, concentrated on grains, ignoring such crops as chickpeas and lentils, the primary sources of protein in the country's vegetarian diet. As a consequence, per capita production of carbohydrates from grain in India tripled. At the same time, largely because of population growth, per capita protein production halved.


JASON HOLLEY

The gains in grain yield came largely from breeding plants with shorter stems, which could support heavier and more bountiful seed heads. To realize this opportunity, farmers poured on nitrogen and water: globally, there was a sevenfold increase in fertilizer use between 1950 and 1990. Now, artificial sources of nitrogen, mostly from fertilizer, add more to the planet's nitrogen cycle than natural sources, contributing to global warming, ozone depletion and smog. Add to this the massive loads of pesticides used against insects drawn to this bulging monoculture of grain, and one begins to see the rough outlines of environmental damage the globe cannot sustain.

During this same revolutionary period, India and other countries, including Mexico, Brazil, Chile and Cuba, developed scientific communities capable of addressing many of their own food problems. High on their list is the promise of genetic engineering *(see "New Markets for Biotech," p. 29)*. In India, researchers have found a natural resistance to pod borers in two other crops, the Asian bean and peanuts, and are trying to transfer the responsible gene to chickpeas. If they are successful, farmers will not only get more protein; they will also avoid insecticides. "The farmer has not to spray anything, has not to dust anything," D. R. Bapat, a retired plant breeder, told me. He need only plant a new seed.

This is the simple fact that makes genetic modification so attractive in

the developing world. Seeds are packages of genes and genes are information—exceedingly valuable and powerful information. Biotech corporations can translate that information into profits. Yet when those same packets of power are developed by public-sector scientists in places like India, they become a tool, not for profit, but for quickly distributing important information. There is no more efficient means of spreading information than a seed.

The above argument built only slowly in my mind in the course of researching a book (*Food's Frontier: The Next Green Revolution*) that profiled nine food projects in the developing world, all of which were carried out largely by scientists native to the countries I visited. I expected to encounter low-technology projects appropriate for the primitive conditions of subsistence agriculture in the developing world—and I did. But I also found, in all nine cases, a sophisticated and equally appropriate use of genetic research or genetic engineering.

A lab in Uganda, for example, could not regularly flush its toilets for lack of running water, but could tag DNA. This tagging ability, used in six of the projects I studied, allows researchers to understand and accelerate the breeding of new strains. Typically, an effort to breed a disease- or pest-resistant strain of a crop can involve ten years of testing to verify the trait. Using genetic markers cuts that time in half—a difference that gains urgency in countries where test plots are surrounded by poor farmers whose crops are failing for want of that very trait.

In this manner, by allowing researchers to accelerate the development of new, pest-resistant sources of protein, genetic engineering can help fulfill the decades-old promise of the Green Revolution. Our last revolution created a world awash in grain. But if Uganda is to get better sweet potatoes, Peru better mashua and India better chickpeas, then research on those orphan crops will have to catch up rapidly. Biotechnology can help.

Food researchers in developing countries are understandably worried they will be hampered by the controversy over genetically modified foods. Meanwhile, they have a hard time understanding why genetic engineering is the focus of such concern. The gains of the Green Revolution, after all—and for that matter the gains of 10,000 years of agriculture—have in many cases come from mating unrelated species of plants to create something new and better. Every new strain has brought with it the potential dangers now being ascribed with apparent exclusivity to genetic engineering, such as the creation of superresistant pests. Genetic engineering merely refines the tools.

When viewed from labs surrounded by subsistence farmers, where food research is a matter of life and death rather than an intellectual debate, genetic engineering is a qualified good—not without problems and dangers, but still of great promise. Genetic modification of foods becomes a natural extension of the millennia-old practice of plant breeding, less environmentally damaging than many modern alternatives. In the end, DNA is knowledge, which we can hope will build to wisdom, from which we may one day create an agriculture that both supports our population and coexists peacefully with our planet. TR

Subsistence farmers expecting a bumper crop will kill themselves rather than face the looming hunger of their families.

Environmental writer Richard Manning's six books include Food's Frontier: The Next Green Revolution *and* Inside Passage: A Journey Beyond Borders.

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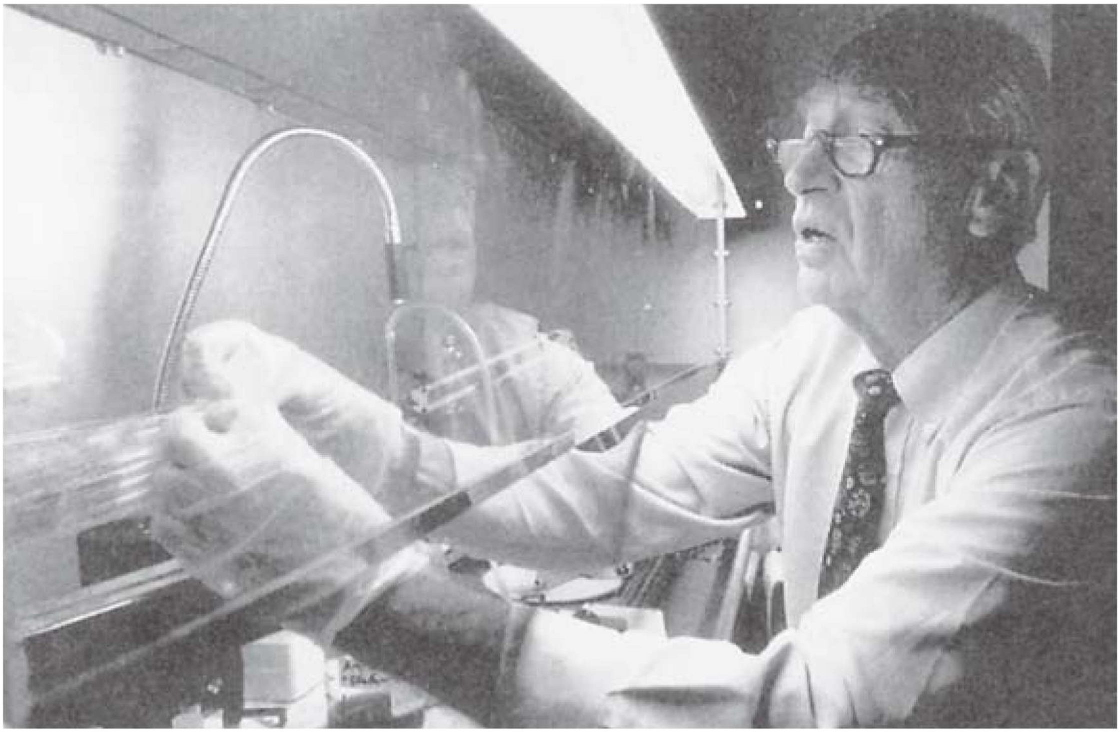

JON GILBERT FOX

Antisense Makes Sense

But it's taken Paul Zamecnik's idea a long, long time

IN THE EARLY DAYS OF BIOtech, all eyes focused on the techniques of "recombinant DNA": splicing together bits of DNA from different sources. These 30-year-old genetic engineering methods are now the basis of a multibillion-dollar market for protein-based drugs. Today, another class of biotech drugs is emerging from the lab, but the technology for these "antisense therapies" isn't new—it dates back to 1978, just a few years after the first gene-splicing experi-ments. A few persistent researchers have shepherded it down a long, bumpy road.

In the early 1970s, Paul Zamecnik (pronounced ZAM-es-nick) was studying a cancer-causing chicken virus that transmits its genetic information via RNA, a chemical cousin of DNA. Zamecnik and his colleagues at Massachusetts General Hospital found that, as the virus replicated, its RNA looped around on itself. They speculated that if they could block this step, they could stop the bug in its tracks. So they constructed a short piece of DNA designed to stick to the virus's single strand of RNA and thereby gum up its works. The RNA encoded the virus's proteins; functionally, it made sense, so the researchers called it the "sense" strand. The DNA molecule (called an oligonucleotide) was its chemical opposite—the "antisense." Zamecnik mixed the designer DNA snippet with infected chicken cells, and voilà—no cancer. He and colleague Mary L. Stephenson suggested that antisense molecules could be used to treat all sorts of infections—as well as cancer—by preventing RNA from being translated into the proteins the invaders need to live.

When the work appeared in the January 1978 *Proceedings of the National Academy of Sciences*, no one believed the experiment had worked. "It had been...a dogma that oligonucleotides didn't get into cells," Zamecnik says. The work languished in obscurity until the mid-1980s, when technological advances made the experiments easier to repeat. As biochemists began to see antisense as a magic bullet, companies sprang up to capitalize on the "new" technology. It wasn't smooth sailing—difficulties with stability and specificity to targeted RNAs hindered its adoption. But now the technique seems ready to pay off. In 1998, the U.S. Food and Drug Administration approved the first antisense drug—a therapy for eye damage caused by cytomegalovirus. More than 20 other antisense drugs, most targeting cancer and viral infections, are in clinical trials. And Zamecnik, now nearly 90 years old, is still researching antisense treatments for drug-resistant forms of tuberculosis and malaria. TR

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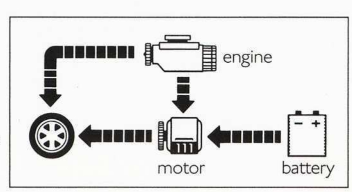

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